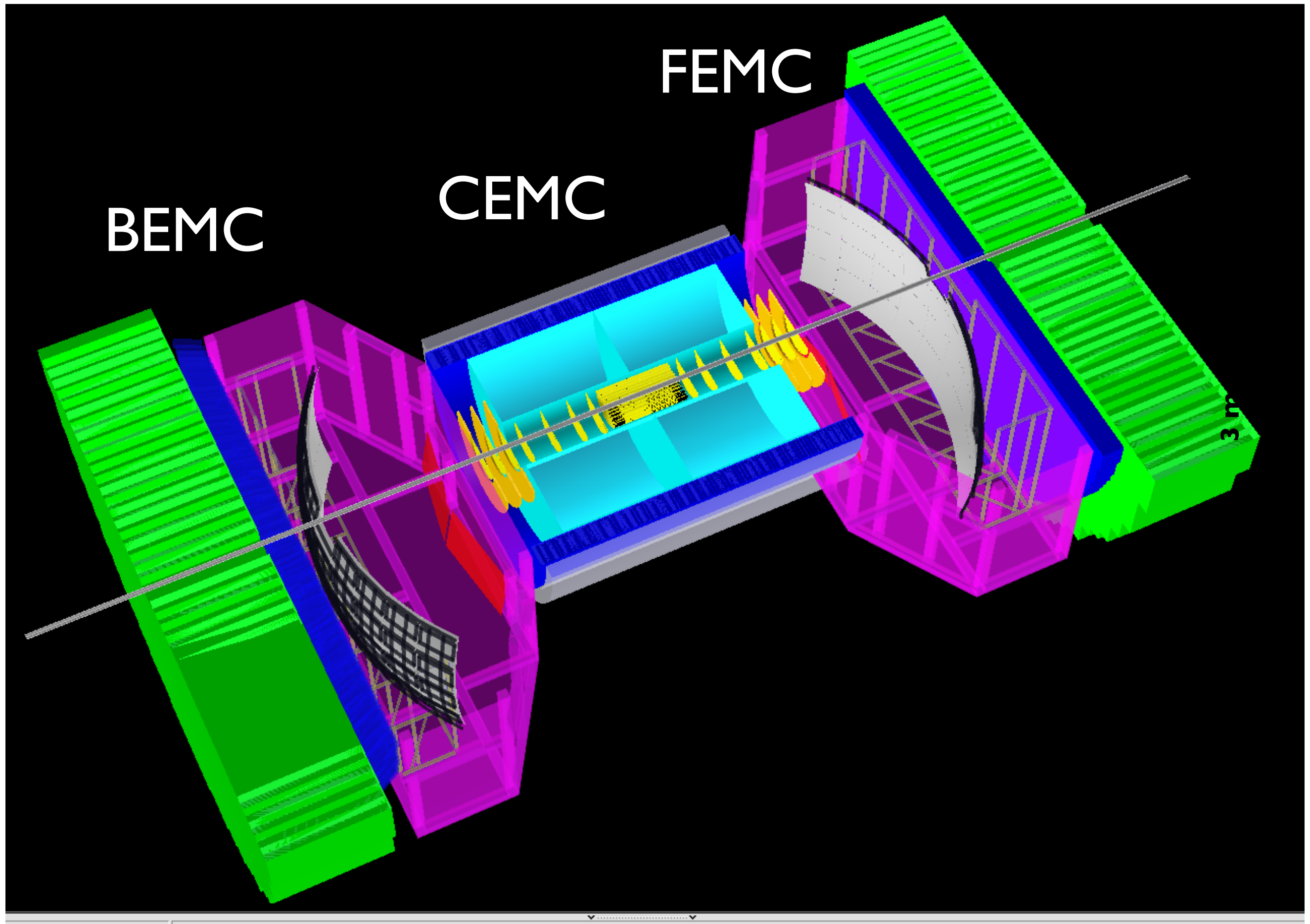
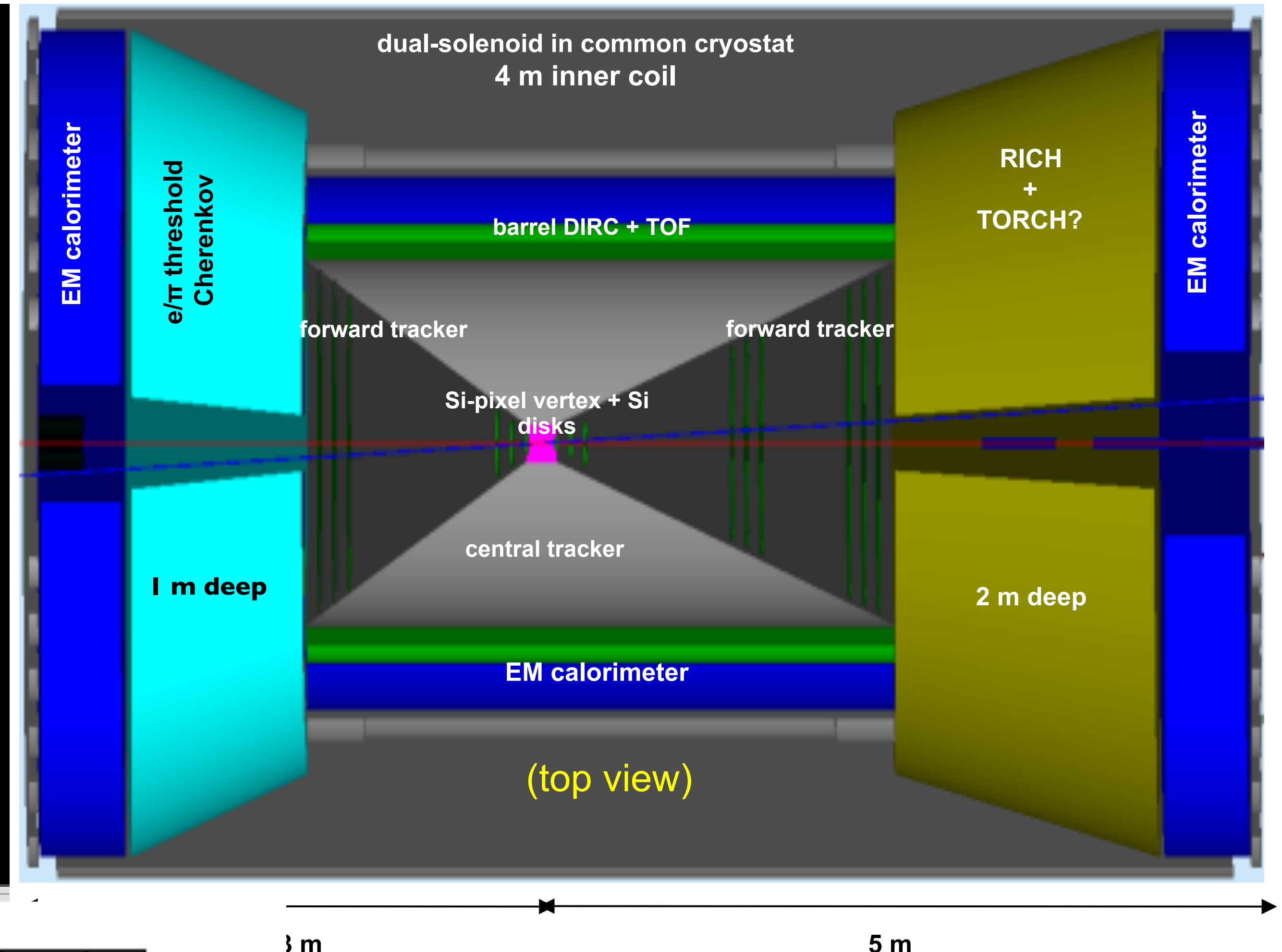
eRD1; Status Report and Proposal for EIC Calorimeter Development

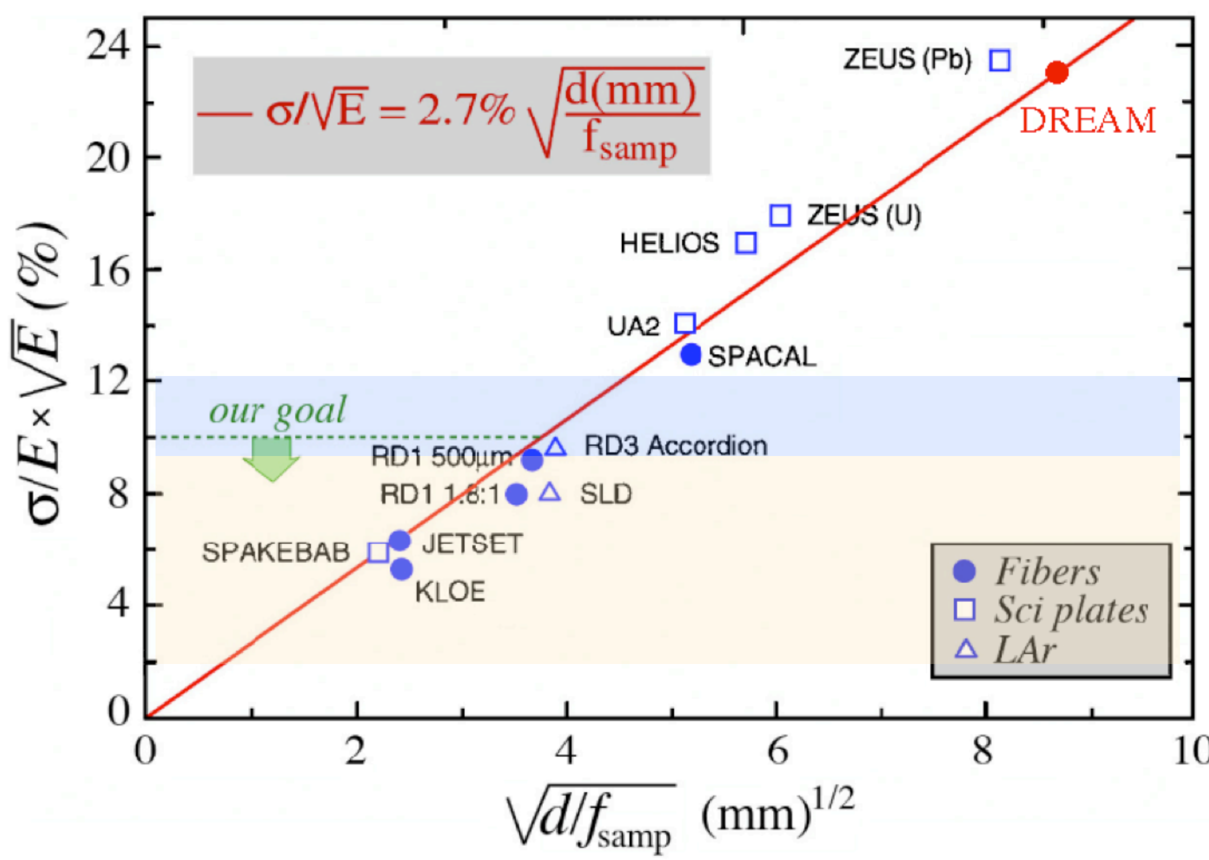
O. Tsai (UCLA), X. Zheng(Jlab)
for RD1 Consortium.

BNL, EIC R&D Meeting, July 9 2015

Conceptual designs of EIC detectors.







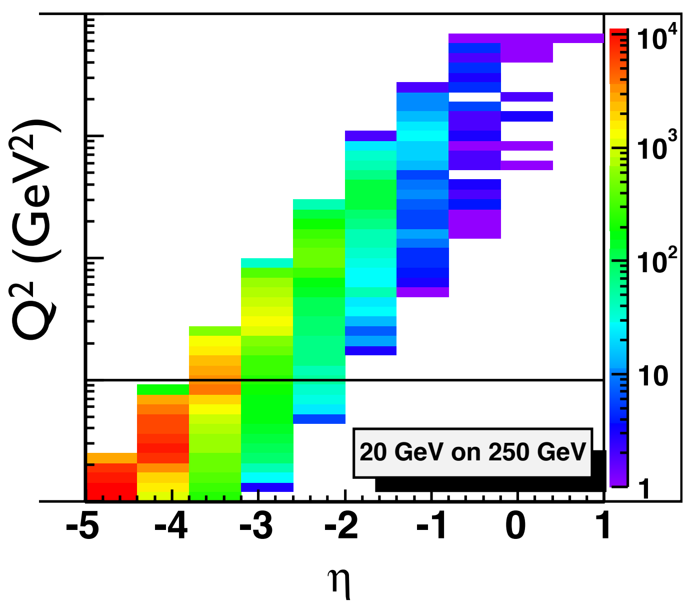
Calorimeters: Full Coverage, Hermetic. Compact. Operate in the magnetic field. Good energy resolution. Good EM+HAD Performance. Fast. Affordable.

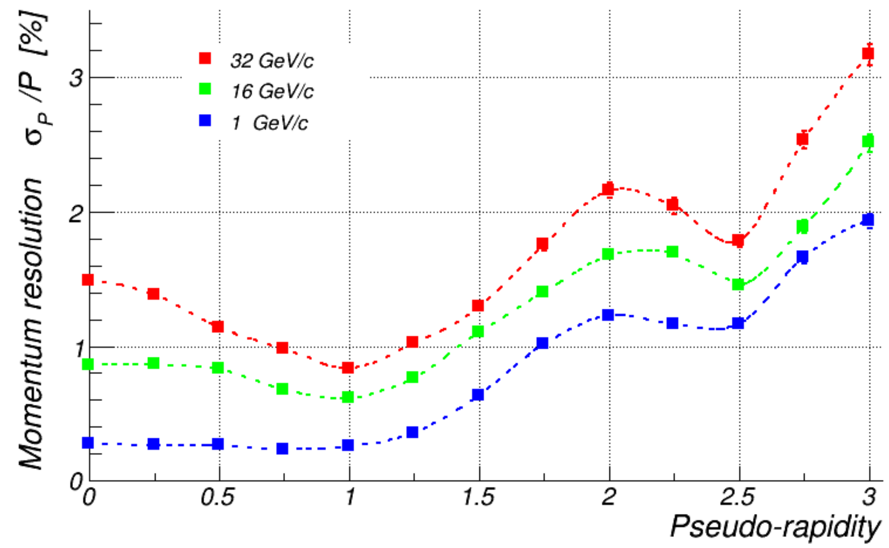
- Central and Forward Emcals
- Back Emcal (Crystals + Sampling)

Global Optimization of Detector/IR drives next phase of calorimeter R&D.

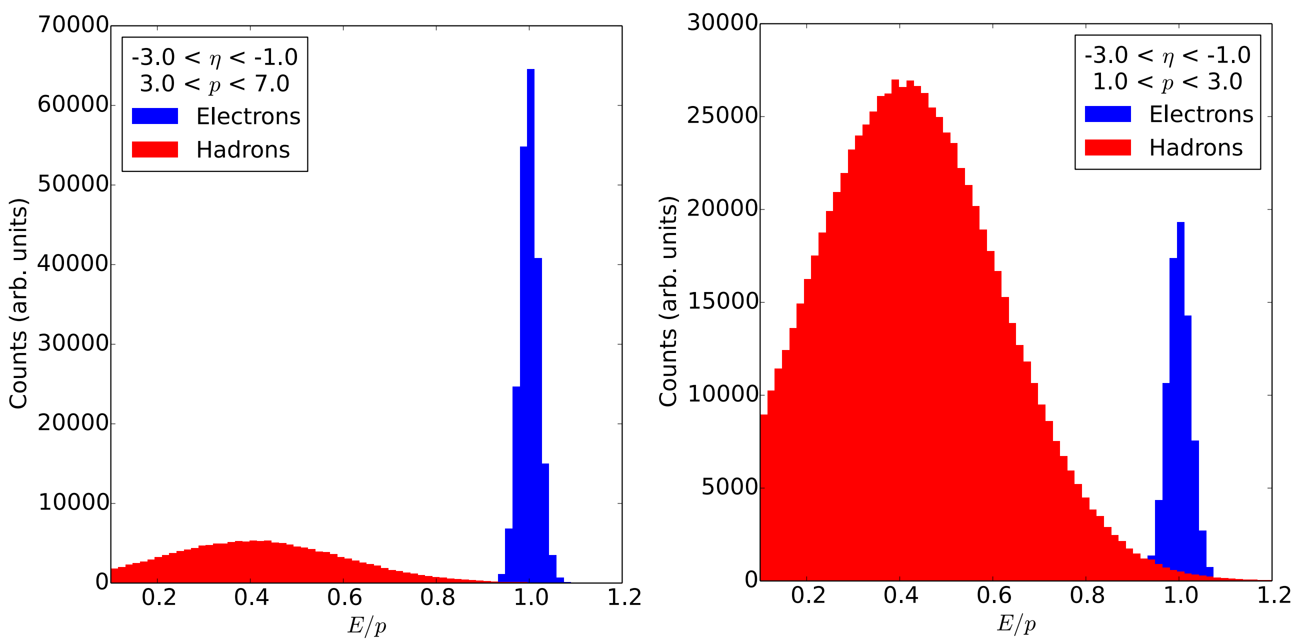
PWO-crystals hard to get
test alternative calorimeters performance
- lead-glass: 5.95% / √E + 0.76% (based on current PHENIX performance)
- tungsten powder ala FEMC: 9.7% / √E + 1.4%

Q^2 ~ 1 GEV → lepton h > -4 still excellent tracking resolution
- main impact e/p

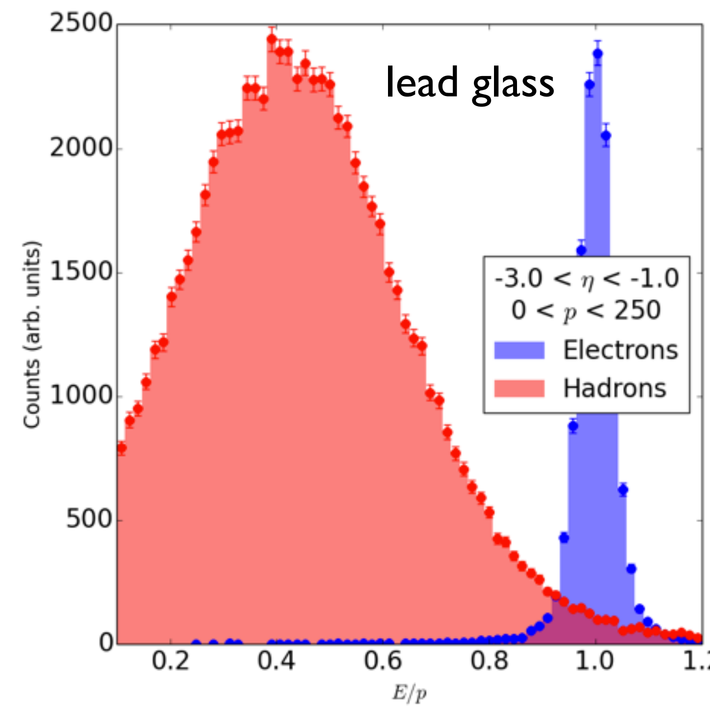




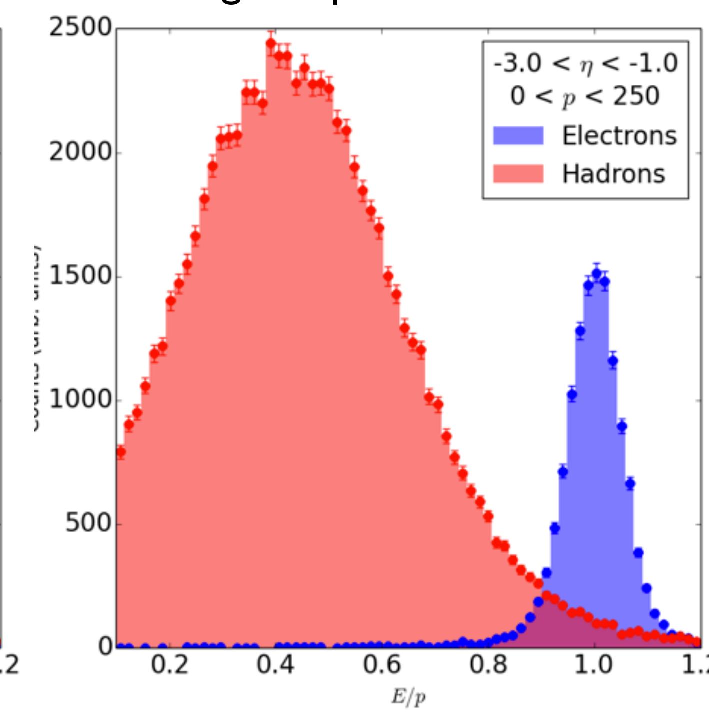
e/p still looks reasonable
→more studies
→Hcal will clean it up



PWO-crystals ala CMS



tungsten powder



What was planned :

1) Develop techniques for producing tungsten powder and scintillating fiber (W/SciFi) based Electro Magnetic Calorimeter (CEMC, FEMC, BEMC).

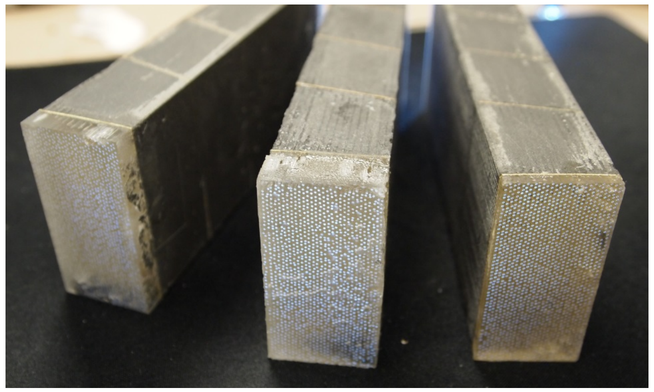
2) Evaluation of Silicon Photomultiplers (SiPMs) as a calorimeter readout sensor and its radiation hardness (CEMC, BEMC, FEMC).

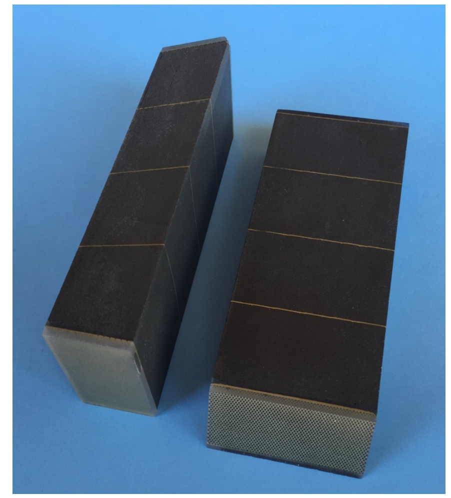
3) Development of a crystal detector at EIC with current focus on PWO crystals and a small effort on continuation of our previous BSO crystal evaluation (BEMC).

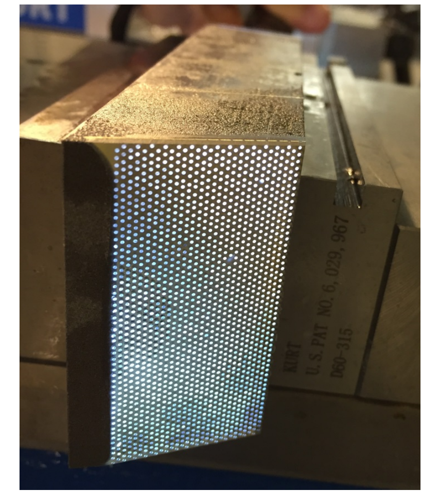
4) Collaboration with the EIC simulation group to develop calorimeter requirements and a quantitative estimate of EIC radiation environment (CEMC. FEMC. BEMC).

What was achieved (technology):

- Technology transfer from UCLA to UIUC, BNL, THP (industrialization). Relevant to CEMC, FEMC (energy resolution ~10%/sqrt(E)).







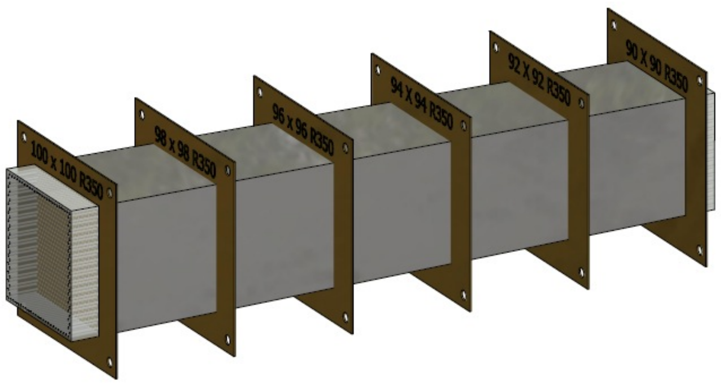
This was mainly a learning exercise in order to become familiar with the construction technique which will then be used to build fully projective modules

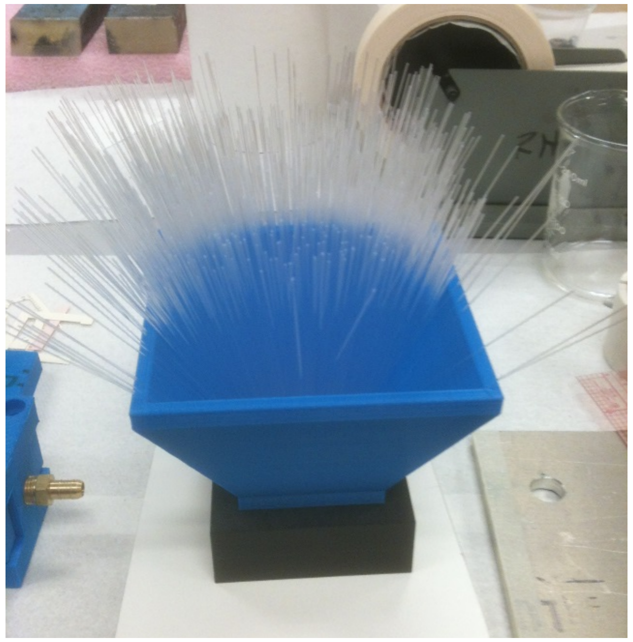
Cutting and polishing ends of module with diamond fly cutter at UIUC.
(one of the first ScFi calorimeter was built by D.Hertzog there)

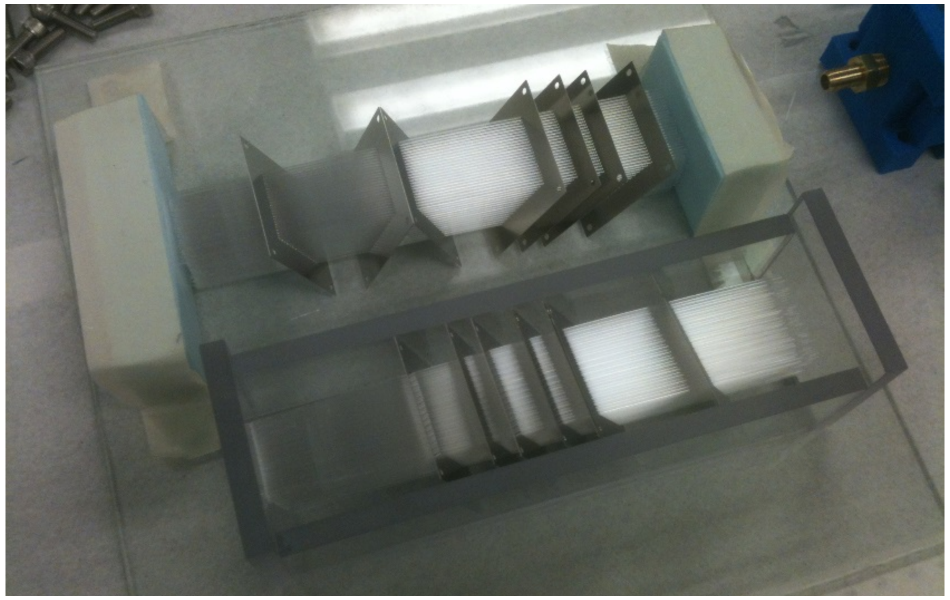
Latest UCLA 'HR' prototype will be sent to IUCF to re-work both ends of the detector with this fly cutter next week.

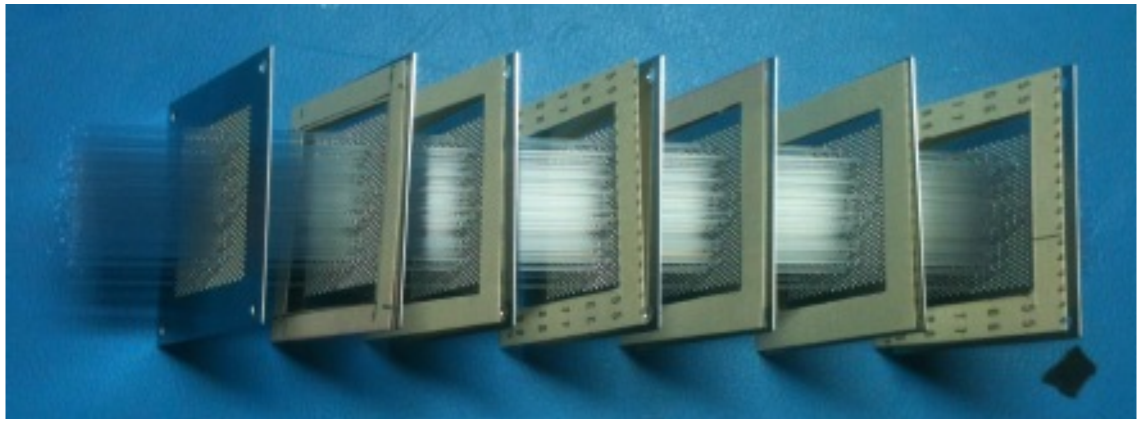
W/SciFi Module Production at BNL

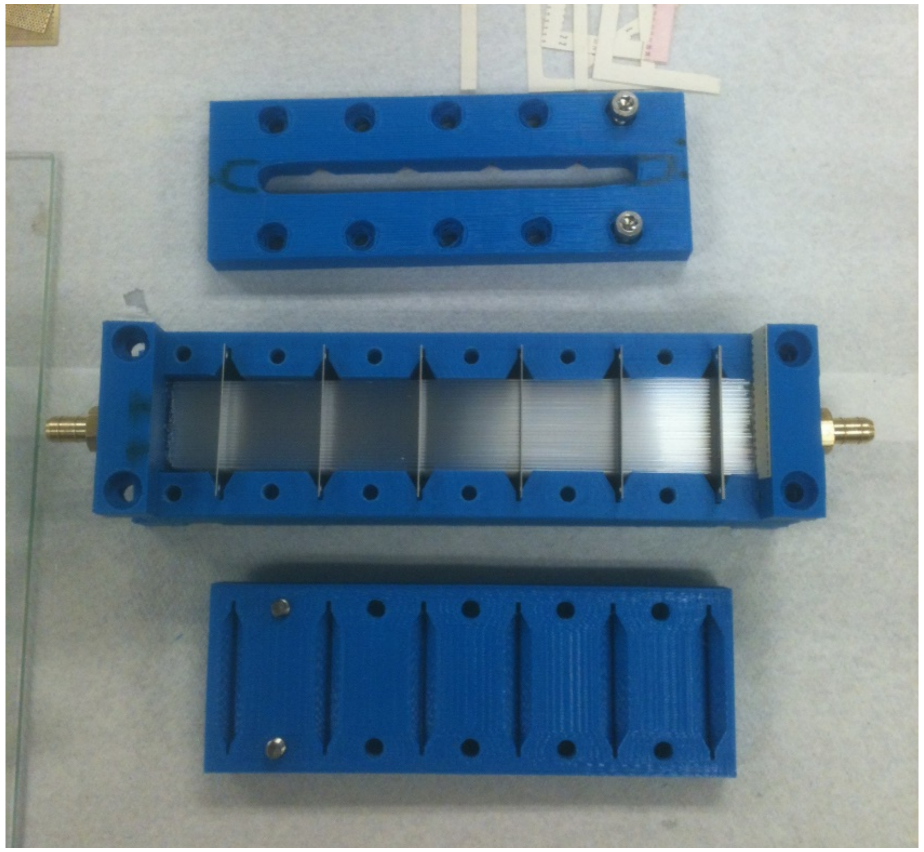
Preparations to Construct Double Tapered Modules











What was achieved (technology):

Investigate W/ScFi technology for high resolution EMCals (~6-7%/sqrt(E))

We increased sampling fraction and sampling frequency (0.667 mm center to center, fibers 0.4 mm in diameter, diluted absorber W 75%, Sn 25%).

Things that we were worried about:
Handling of (25k) thin long fibers during packing through set of screens – OK
Mould release due to increased length of the detector (25 cm) – OK
Thermal runaway of epoxy during curing – OK

Test Run 2015 FNAL, May 19-29(UCLA, BNL, TAMU, PSU):

Golas: Test new 'HR' prototype, Test Old prototype equipped with new light Collection scheme.

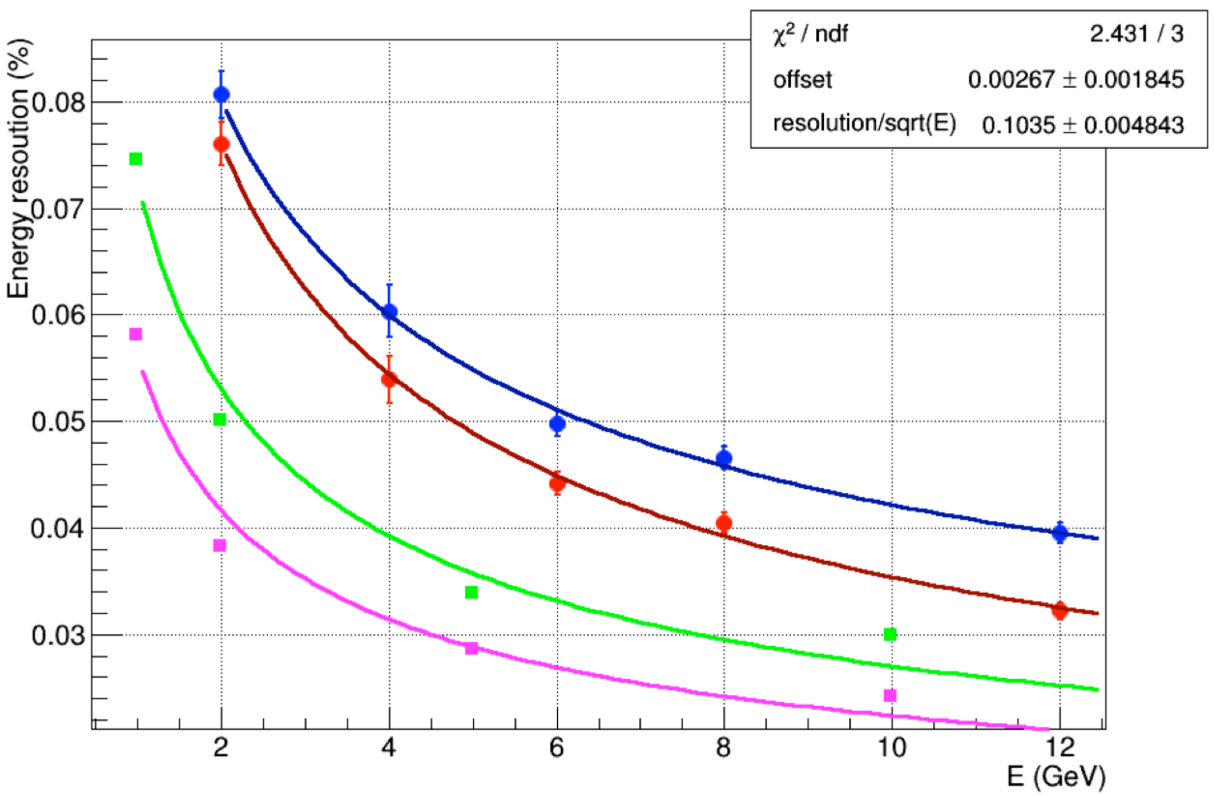


Figure 3 Energy resolution in EM prototype compared with MC predictions.

Magenta – Ideal MC for Test Beam prototype.
Green -Ideal MC + 460 p.e./GeV
Blue – raw experimental data.
Red – dp of beam subtracted

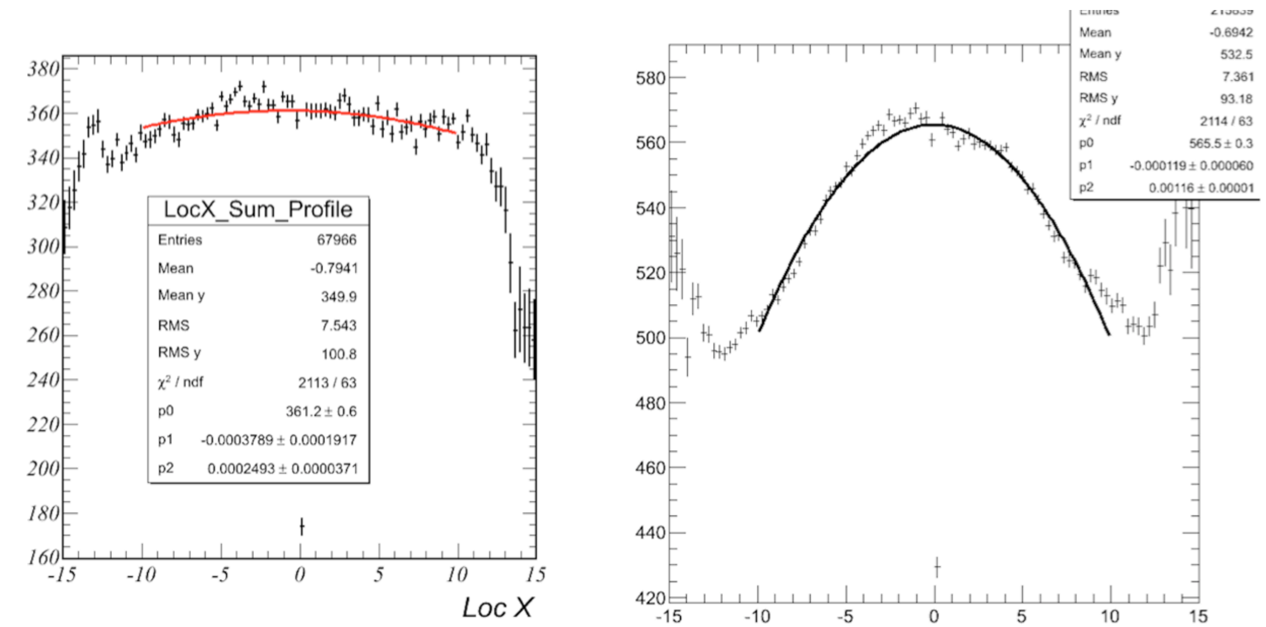


Figure 6. Response of the old EMcal to 4 GeV vs impact point. Left 2015 data, right 2014 data.

- Compensation filter between fibers and SiPMs did flatten response as expected
- Light loss 30% vs 15% as was expected

- Light Yield 460 p.e./GeV vs expected 900 p.e./GeV
- Big difference between expected (Green curve) and measured (Red curve), not yet explained.

Test Run 2015 FNAL, no smoking gun found except of low LY:

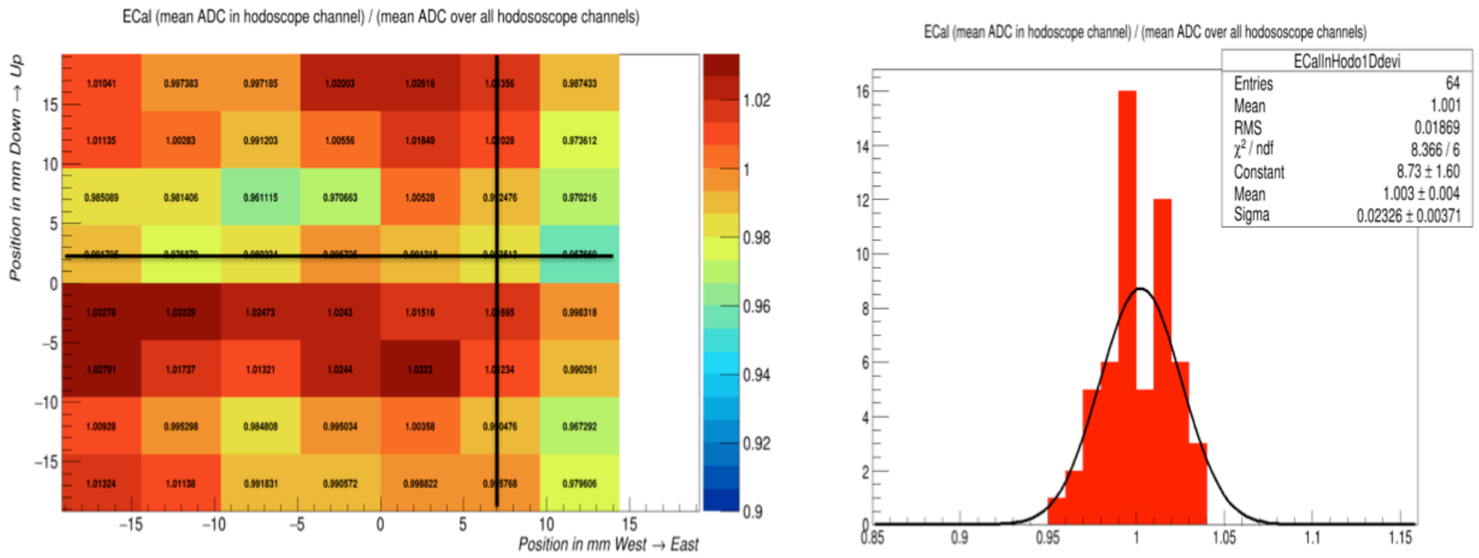


Figure 5. The uniformity of response across the face of the detector is 2.3% for 4 GeV electrons.

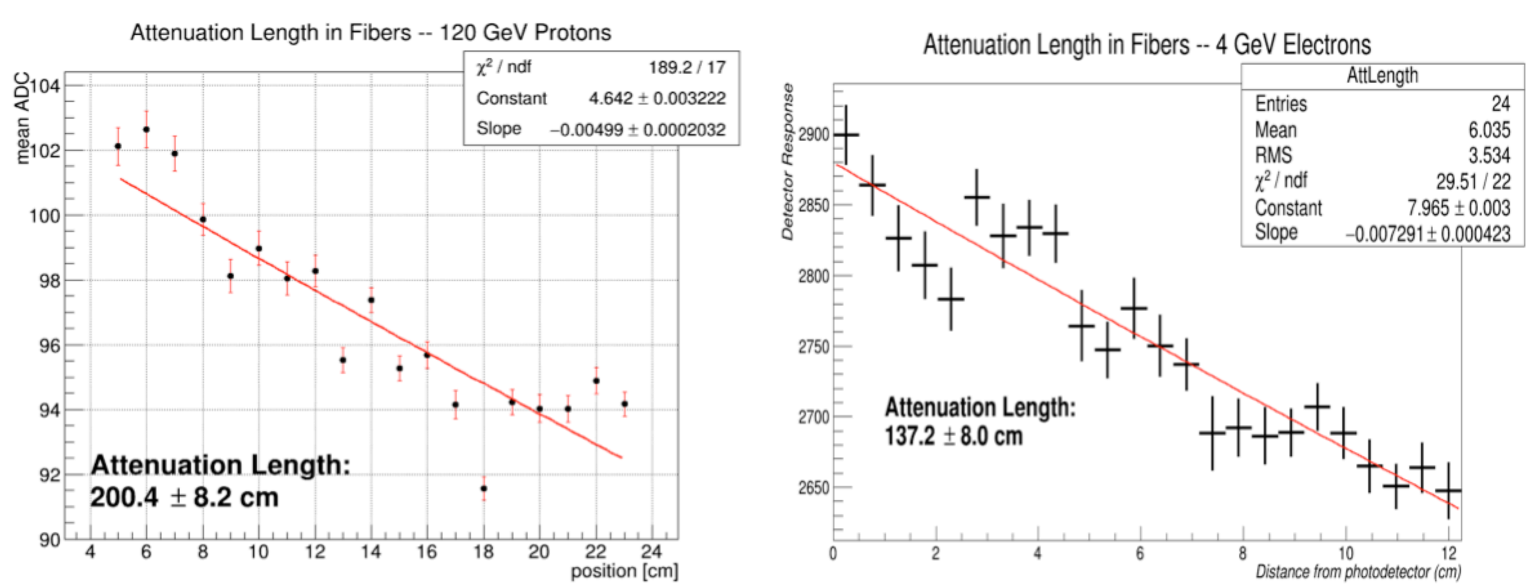


Figure 4. Attenuation length in 0.4 mm scintillation fibers measured in the test run.

Scans along the towers with 120GeV protons and 4 GeV electrons, and measurements of transverse non-uniformities in the response did not pointed to a definite problem.

Possible explanations:

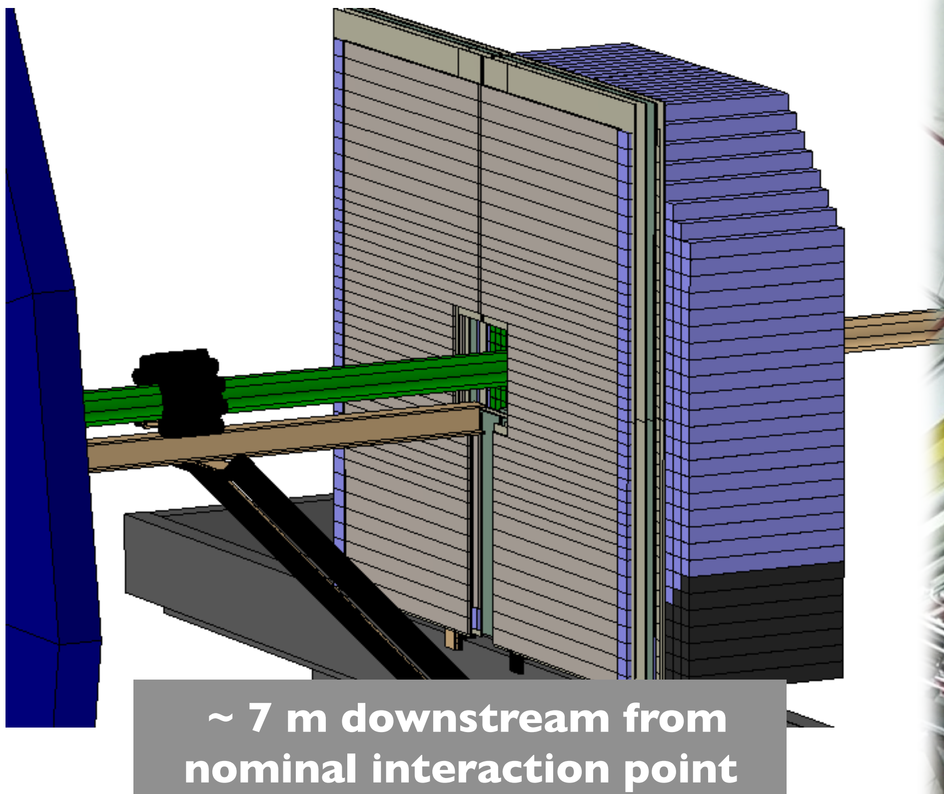
1. Damages at tips of fibers due to straight cut trough Absorber/Fiber mixture (by mistake), that was not in all other prototypes.
2. Non-uniformities in composite absorber.
3. Imperfections in the filter and compact readout scheme.

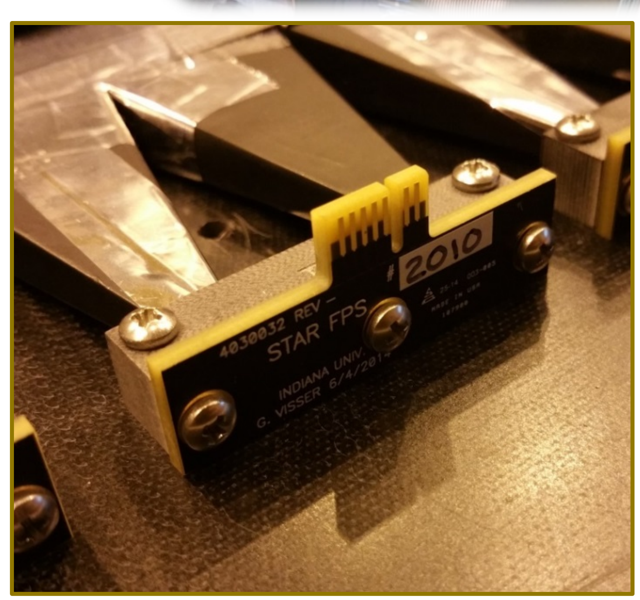
- Transverse non-uniformity of response is 2.3% vs 1.4% in SPACAL tested in 2012 with PMT readout.
- Attenuation Length similar to what was measured for 0.47mm fibers in previous SPACAL.

- Looking back, mistake was made of combining few new things at once and pushing resolution dow, should have been using 2012 approach one step at a time!

SiPM Rad Damages Studies:

- Run 15 STAR FPS (Forward Preshower Detector) first time SiPMs used for Physics Measurements at RHIC.





3 Hodoscope layers, each 84 channels.
3mm x 3mm Hamamatsu MPPC
50um cells in layer 1 and 2
25um cells in layer 3

Very successful project. Smooth operation from 'Physics' day one in pp, pAu, pAl.

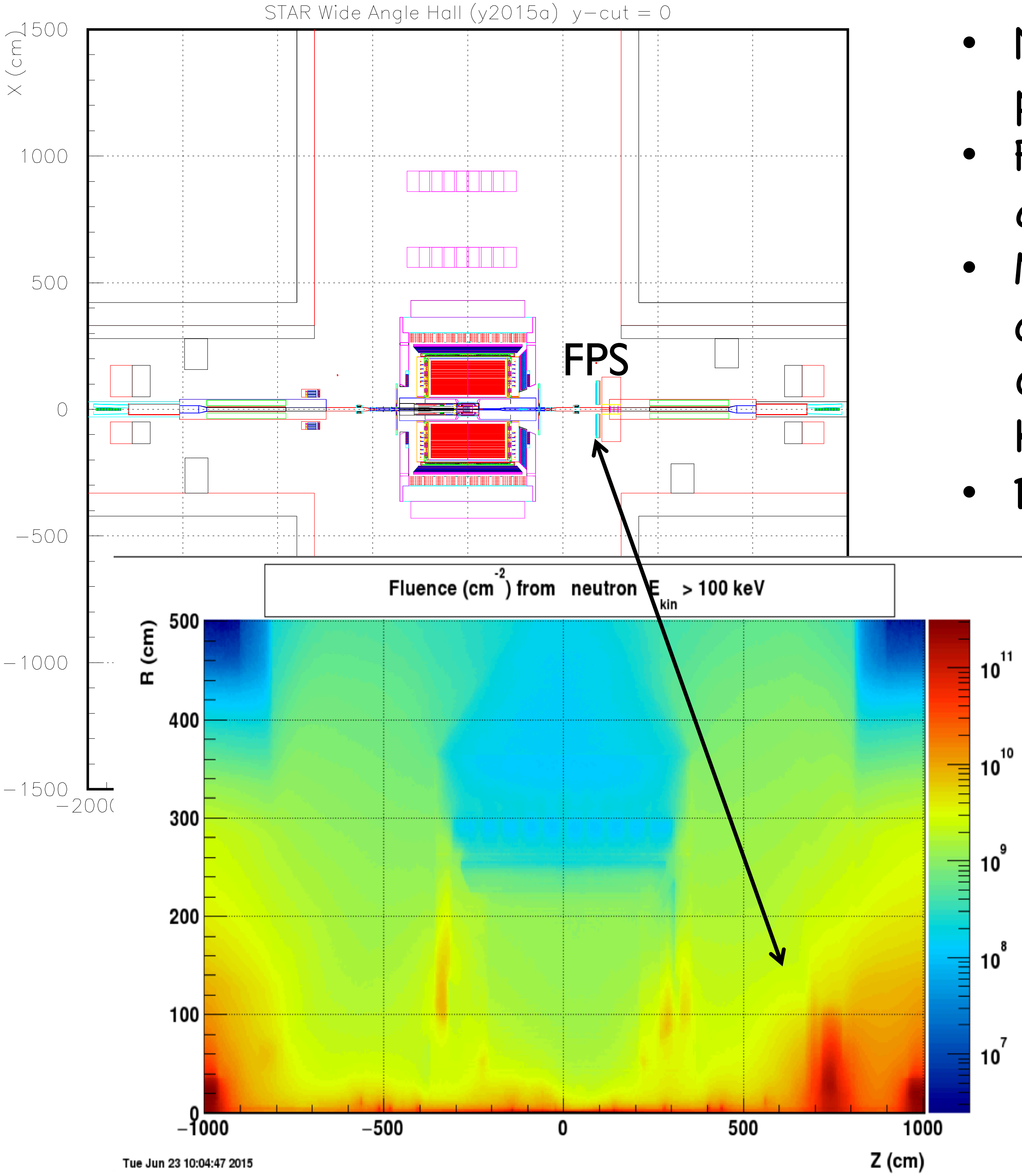
Operated by STAR detector operators.
Daily pedestal runs, I/V scans.

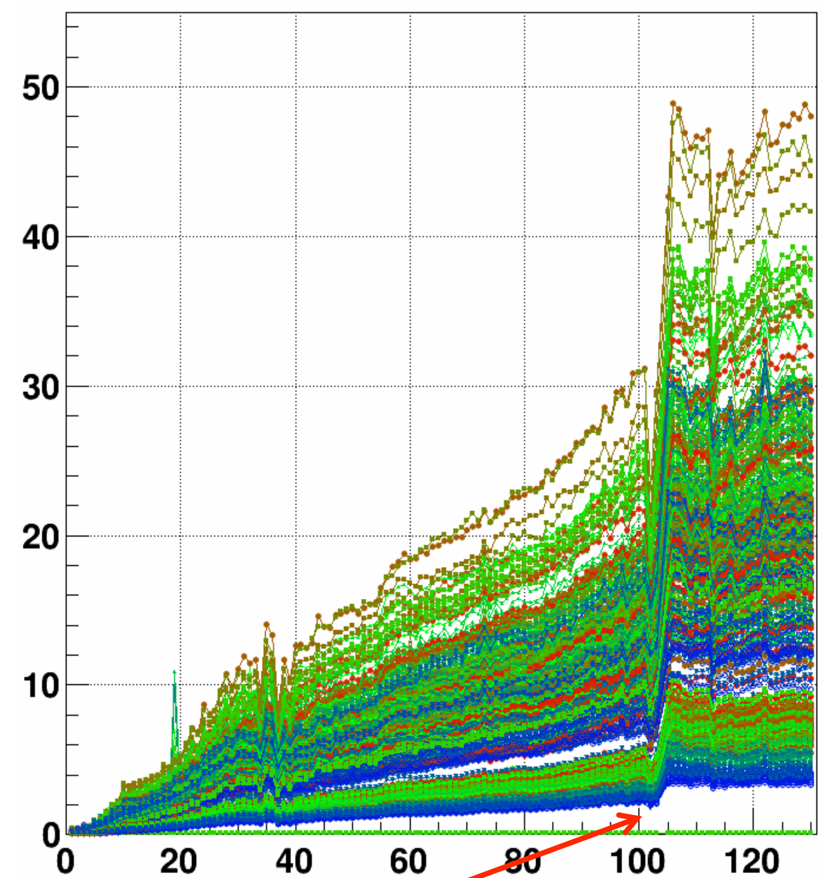
3 sets of 10 TLDs were installed around FPS/FMS (each set stayed ~4 weeks, data still under analysis).

For pAl added CERN RadMons (similar to one used at PHENIX IP)

Neutron Fluxes:

- Neutron fluencies calculated for pp, pAu, pAl for integrated delivered luminosity.
- FPS SiPMs were exposed to 10^{10} n/sm^2 according to our MC.
- MC doesn't know about beam losses, APEX or high background during steering, collimations etc., i.e. real exposure is higher than MC gives.
- Data from TLDs still in processing.

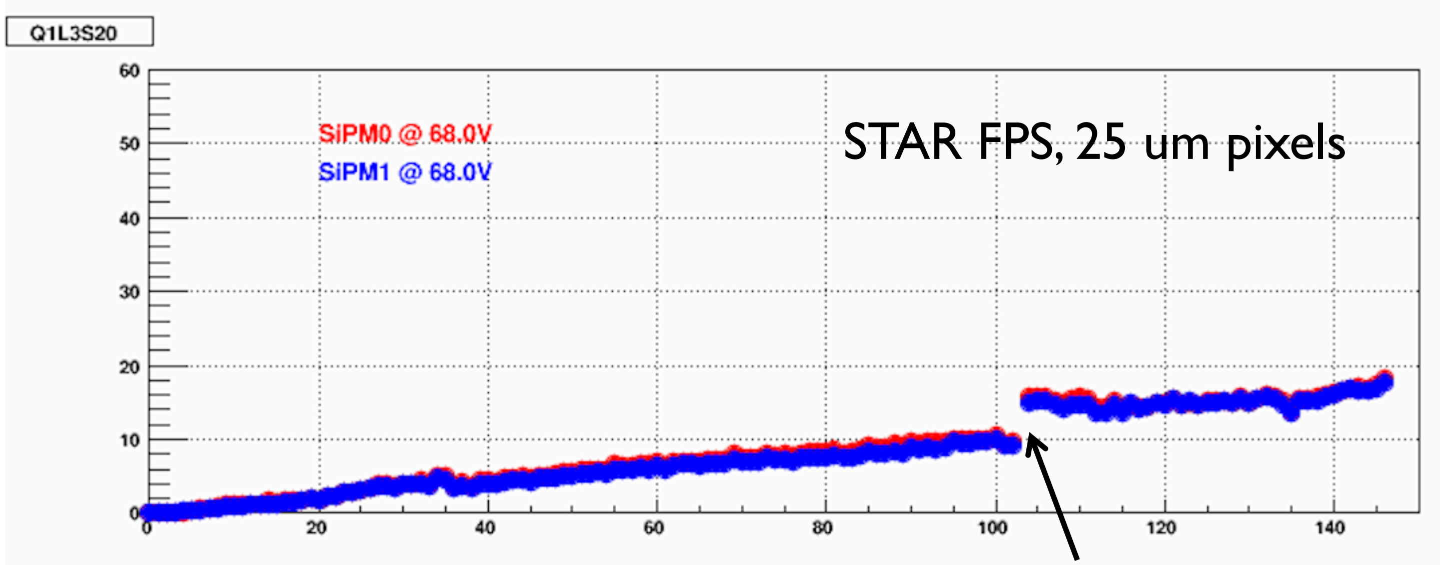




May3rd when beam blasted in WAH

~5weeks pp running worth of rad damage in 1 day

SiPM Leakage Current vs neutron fluence:



10^{10} n/cm^2

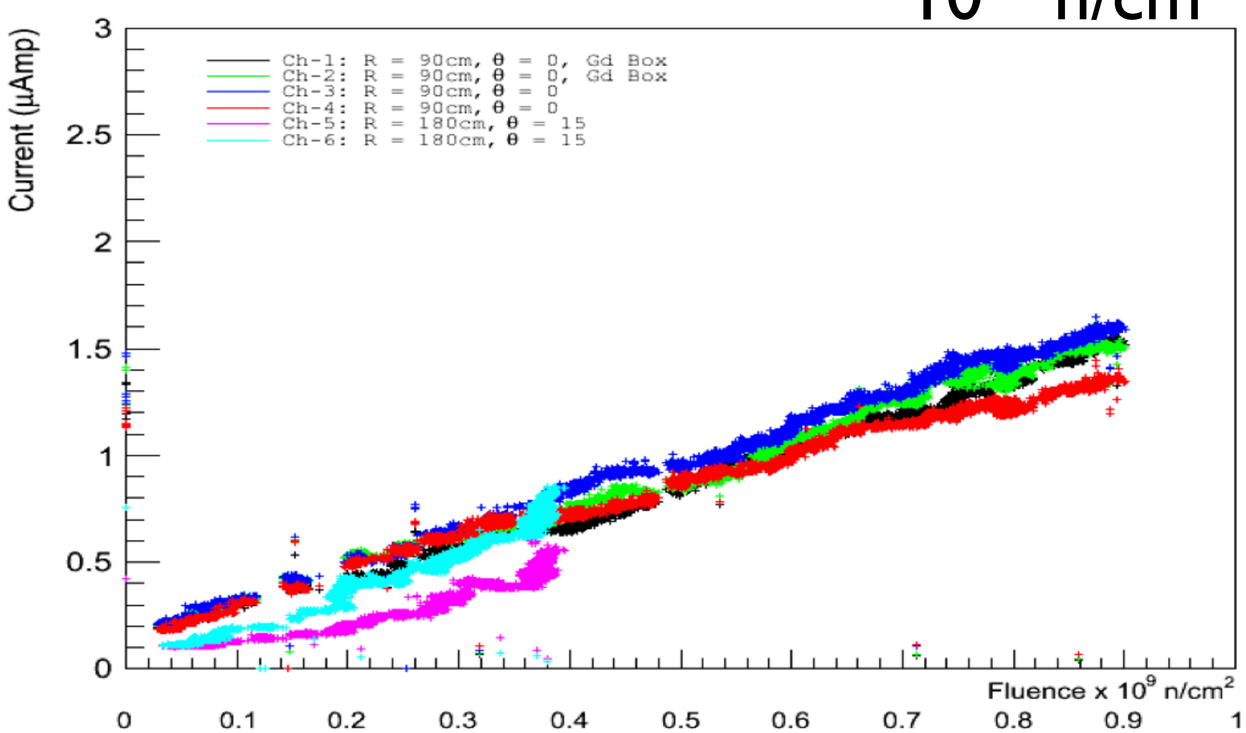


Fig. 8. Hamamatsu S12572-015P SiPMs placed in the PHENIX IR during the current RHIC run. Channels 1&2 were enclosed in a Gd box that absorbed all thermal neutrons. Channels 3&4 were unshielded in the same location. Channels 5&6 were also unshielded and located at the base of the central magnet next to a SPACAL block.

M. Moll Phd.Th.

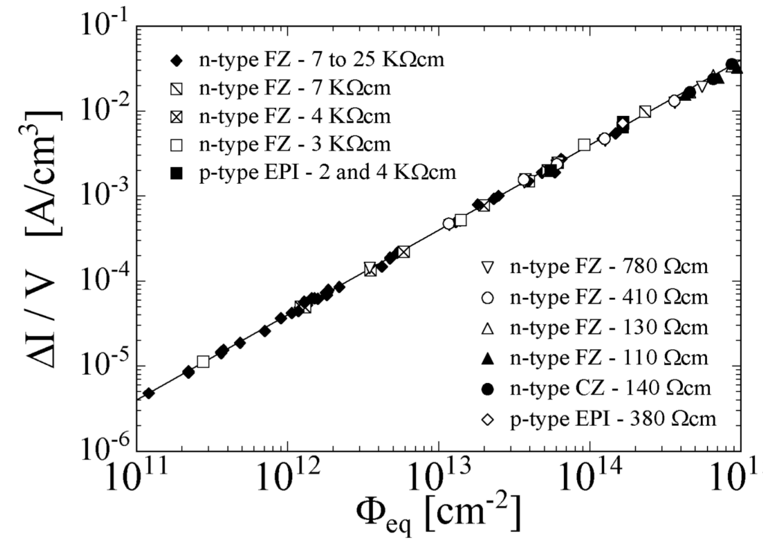


Figure 5.1: Fluence dependence of leakage current for silicon detectors produced by various process technologies from different silicon materials. The current was measured after a heat treatment for 80 min at 60°C $\{\alpha(80\,\text{min}, 60°\text{C}) = (3.99 \pm 0.03) \times 10^{-17}\,\text{A/cm}$; for details see Fig. 5.6$\}$.

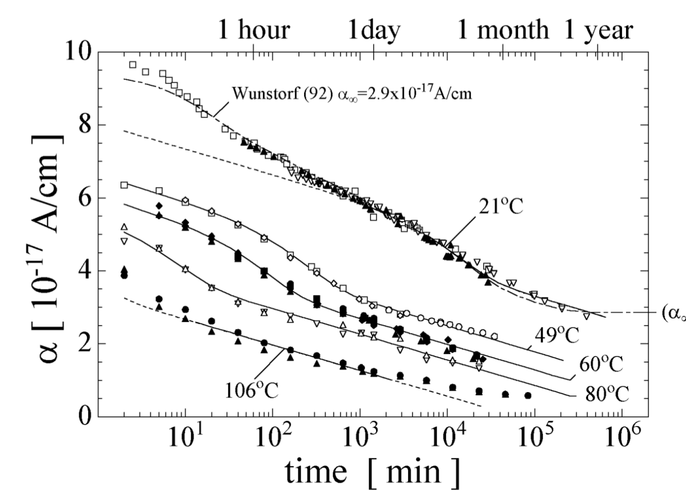


Figure 5.2: Current related damage rate α as function of cumulated annealing time at different temperatures. For each temperature at least one type inverted and one not type inverted sample has been used. The dashed-dotted line represents a simulation according to Eq. 5.3 with parameters as given in Tab. 5.1 and α_∞ as displayed in the figure. The solid lines are fits according to Eq. 5.4. (Samples of type WE-7kΩcm and WE-25kΩcm; see Tab. 4.1)

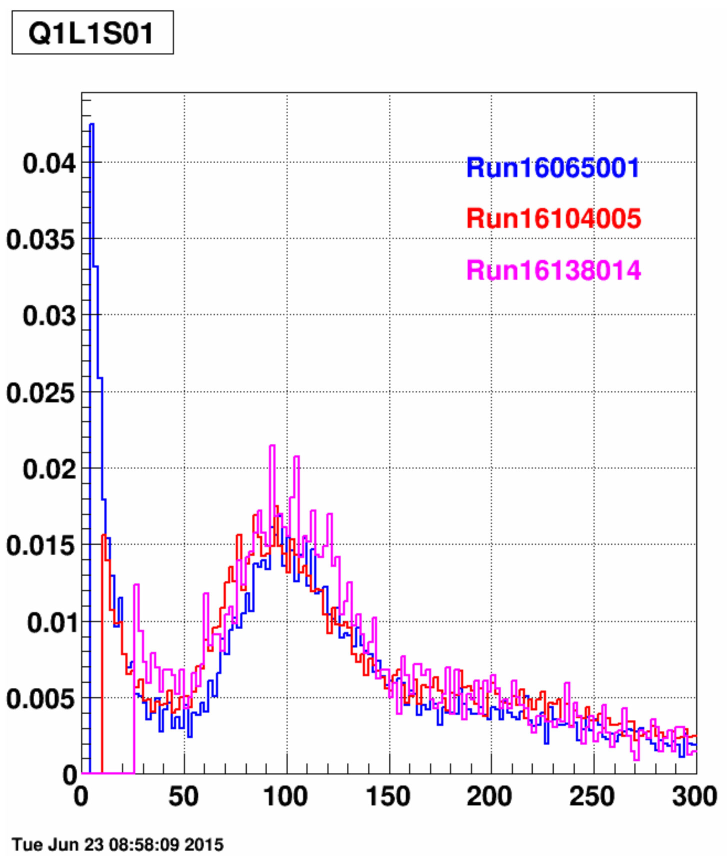
$$\Delta I = \alpha \, \Phi_{eq} \, V$$

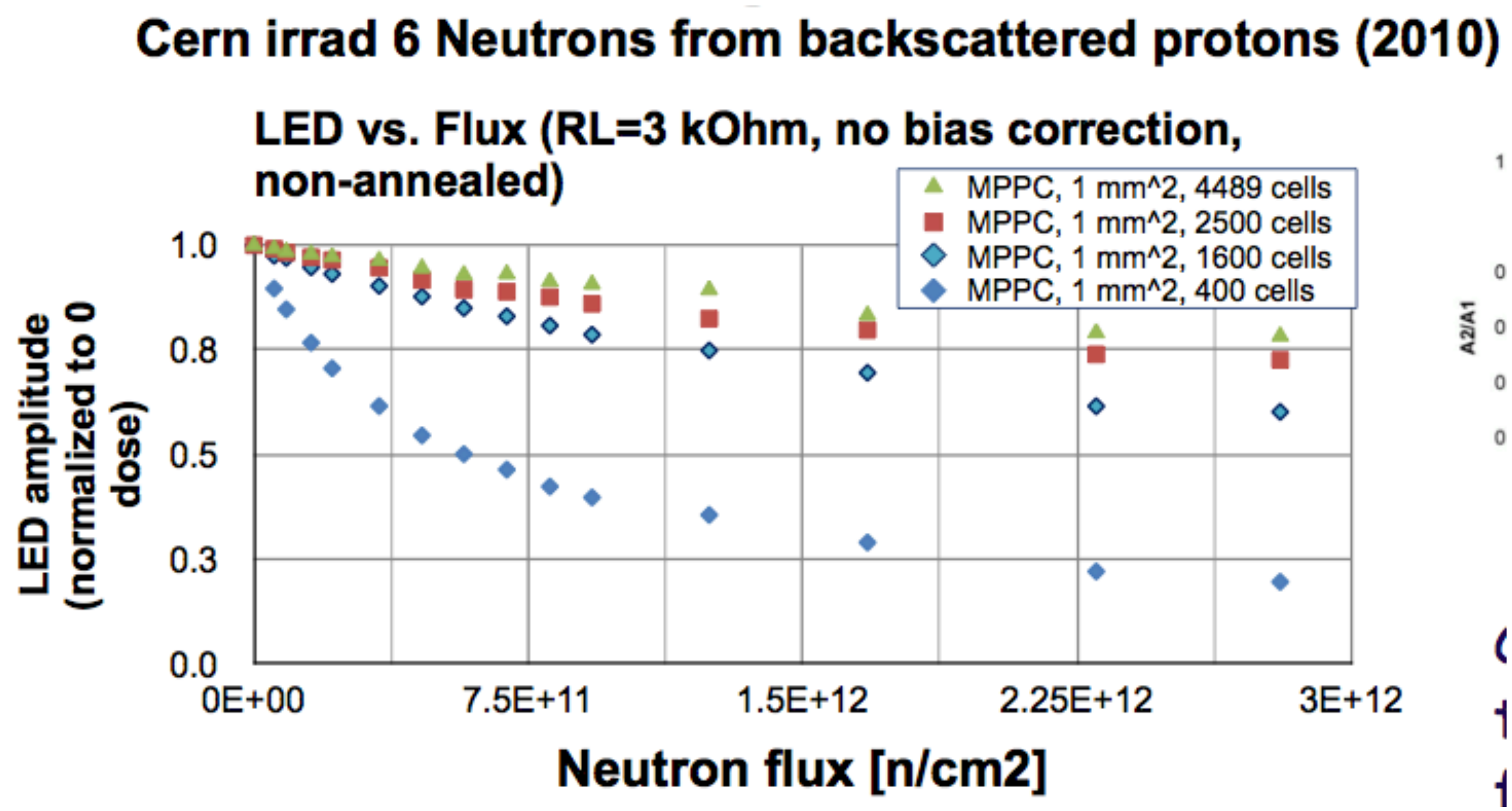
- STAR FPS alpha = 3.5 * 10 $^{-17}$ A/cm
- Thickness of depleted region ~5 um
- At 10^{10} n/cm^2 I = 5 uA

In general good agreement with M.Moll and CMS data.

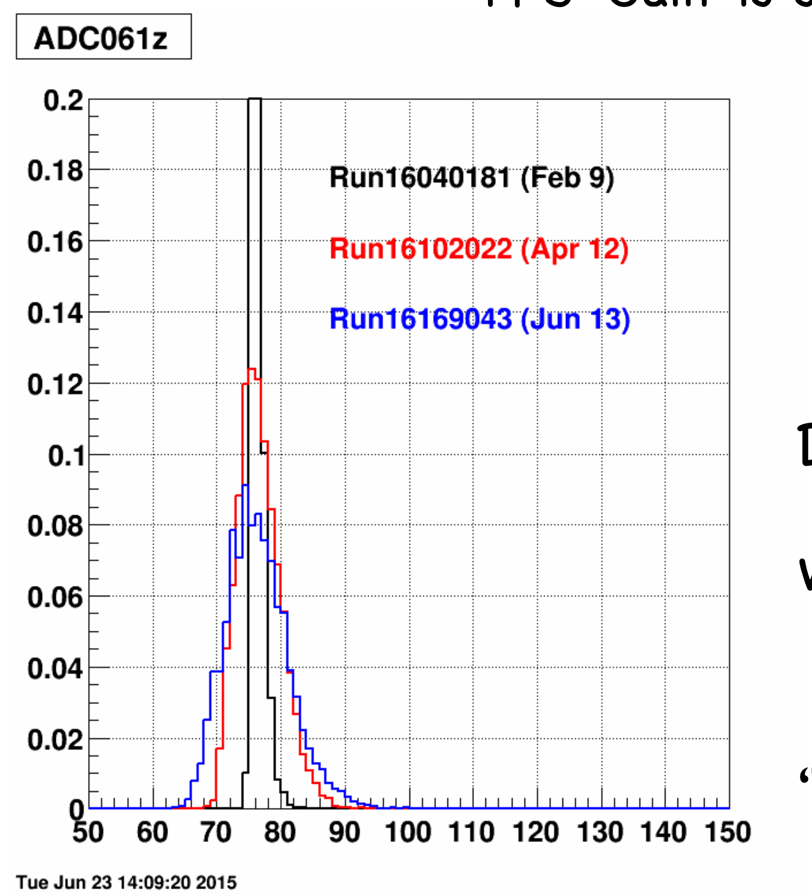
'Gain' Stability, Noise :

Y.Musienko, Pisa Poster 2015





FPS 'Gain' is stable at fluencies 10^{10} n/cm^2, in agreement with CMS data.

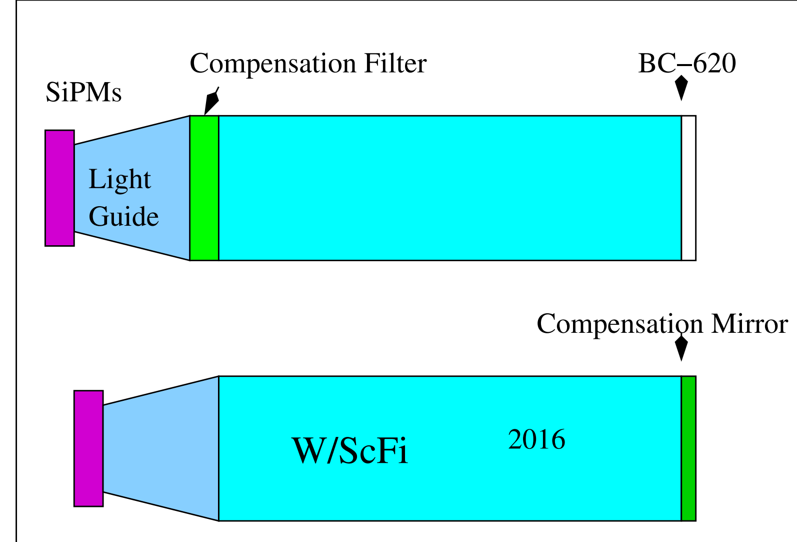


Two 3x3 mm2 Hamamtsu 25 um pixels SiPMs per channel.

Due to increase dark current noise in ~65 ns integration window increased from 1 p.e. to ~ 5 p.e.

'Testing' new detectors in real experimental conditions.

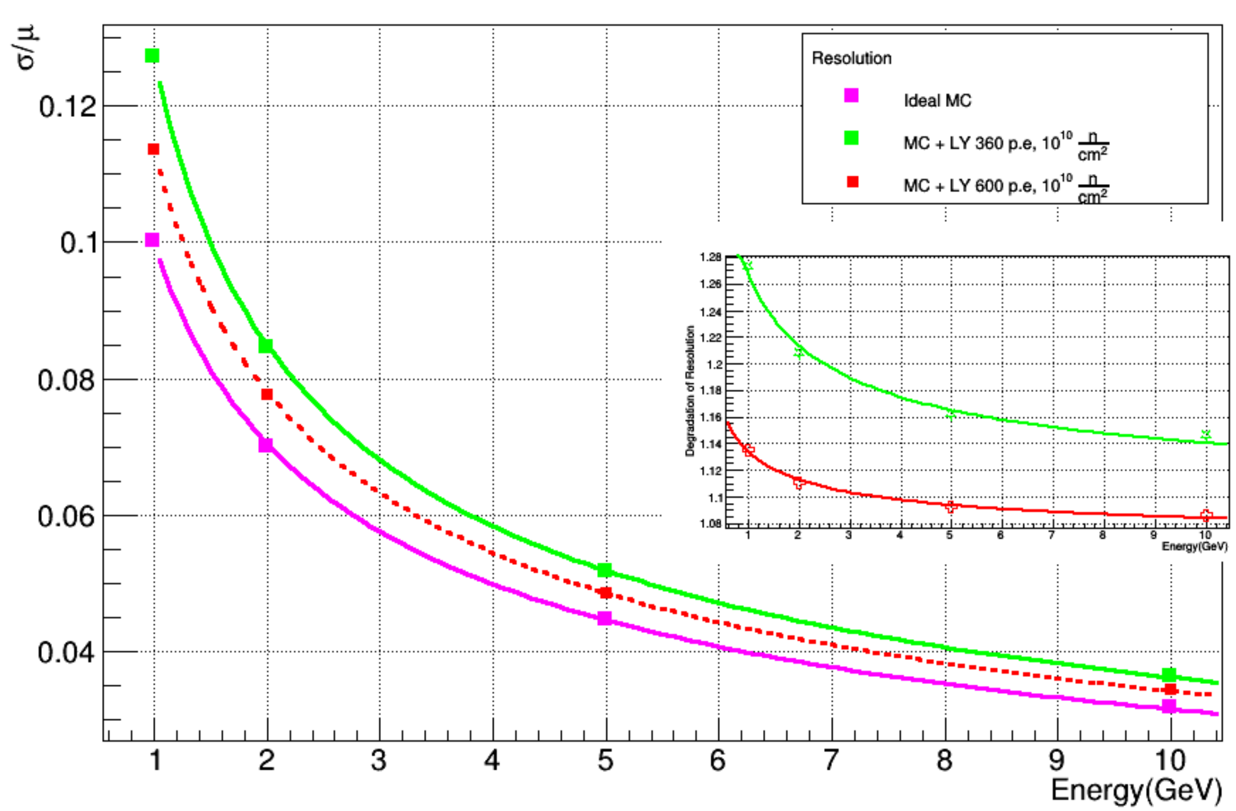
Projected calorimeters performances:



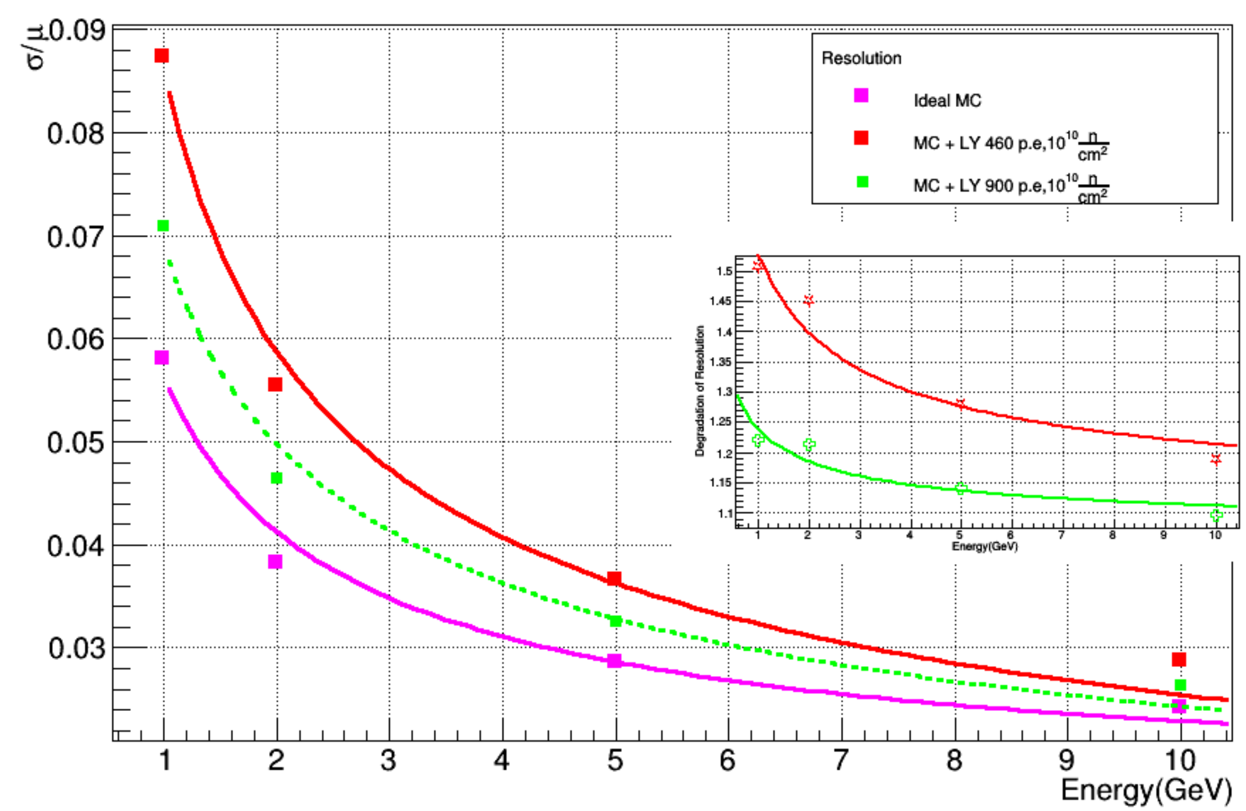
Proposed change in light collection scheme.

- Cluster 3 x 3 towers, 4 SiPMs per tower. Noise after 10^{10} n/cm^2 ~ 21 p.e.
- FEMC, CEMC – Light Yield in hand ~ 360 p.e.
- FEMC, CEMC – Light Yiled possible ~ 600 p.e. (better PDE on new sensors, refined light collection scheme)
- Compensation in light collection scheme should be made on the back side

Readout 4 SiPM per Tower (FEMC,CEMC)



Readout 4 SiPM per Tower (BEMC)

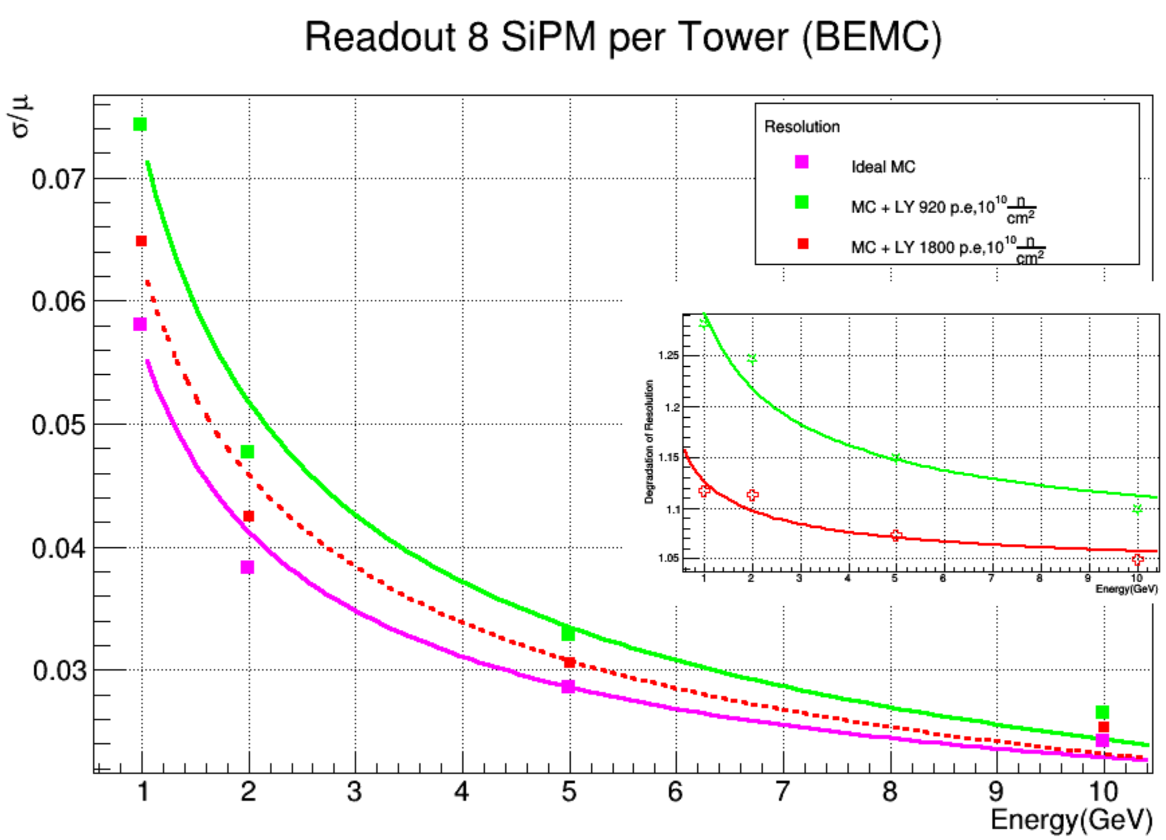


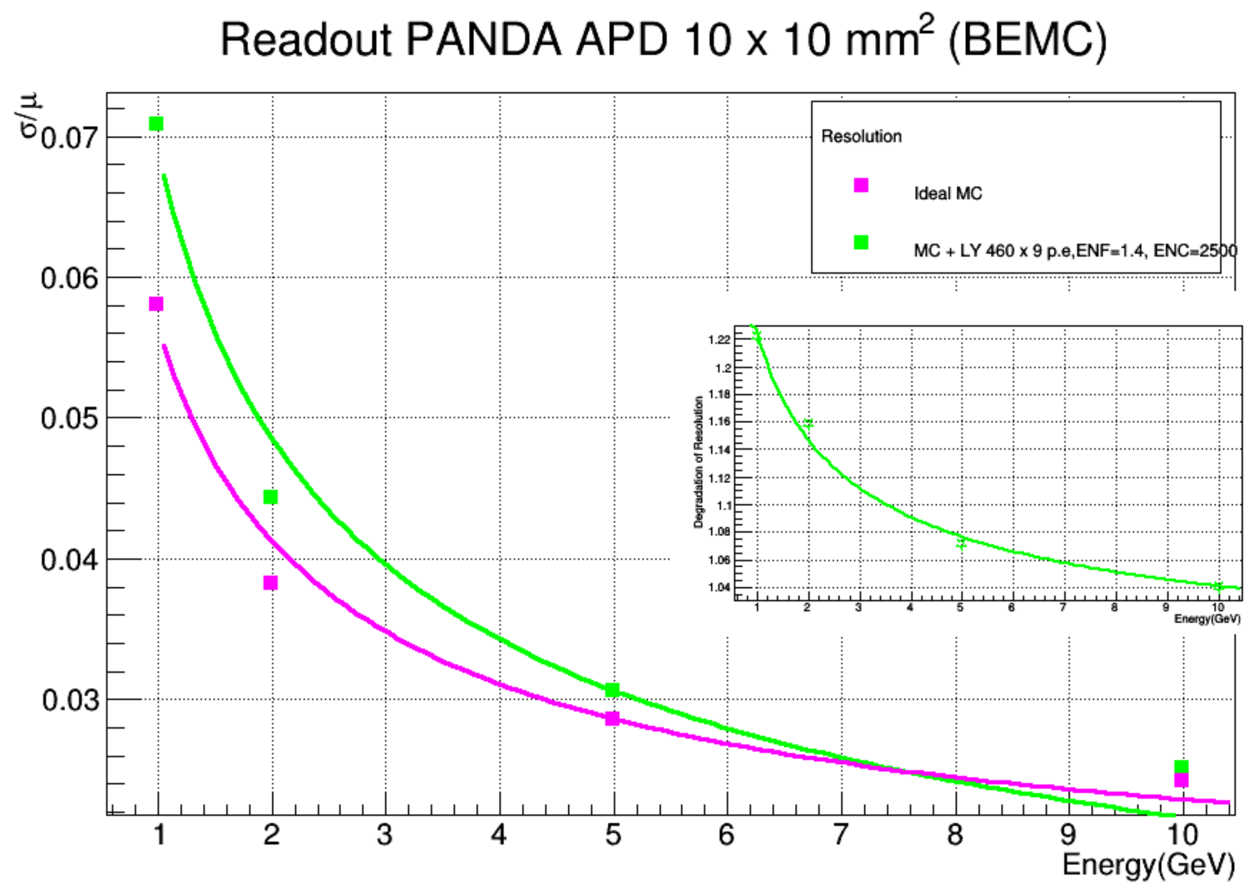
BEMC – Light Yiled possible ~ 900 p.e. (better PDE on new sensors, refined light collection scheme), which is not enough.

And still very puzzled with 460 p.e. measured in test run 2015, worrying about thin Sc. Fibers.

Possible schemes of improvements for 'HR' BEMC:

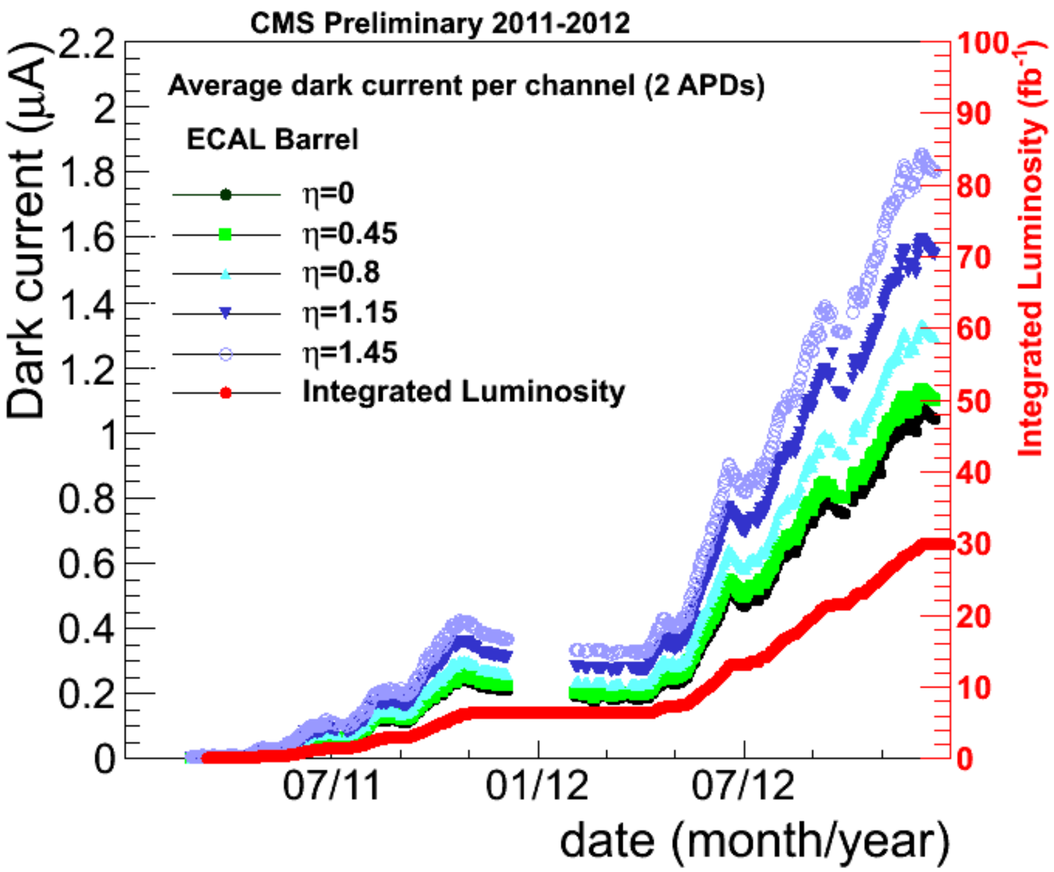
- Cluster 3 x 3 towers, 8 SiPMs per tower. Noise after 10^{10} n/cm^2 ~ 30 p.e.
- BEMC - Light Yield assumed ~ 460 x 2 p.e.
- BEMC - Light Yiled assumed possible ~ 900 x 2 p.e.

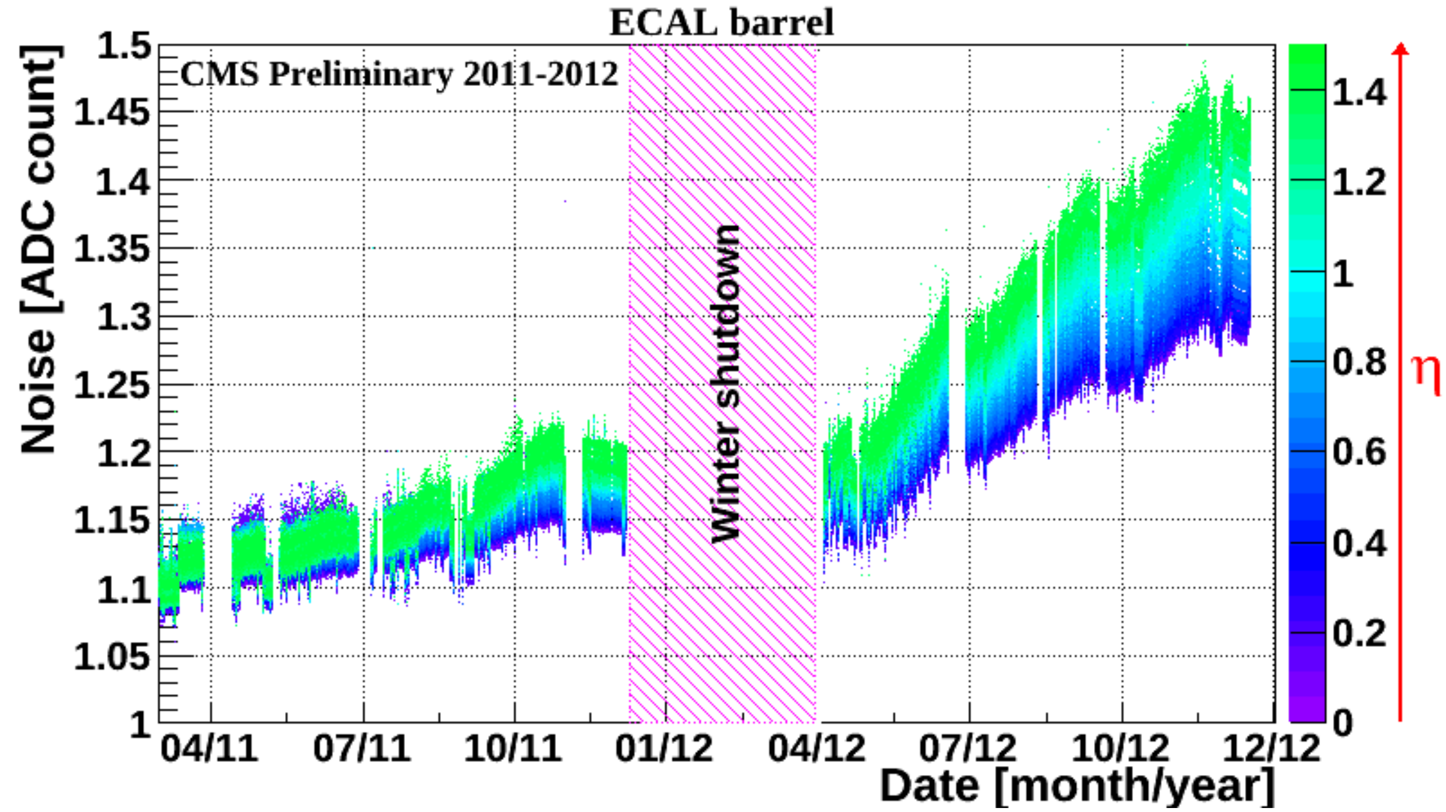




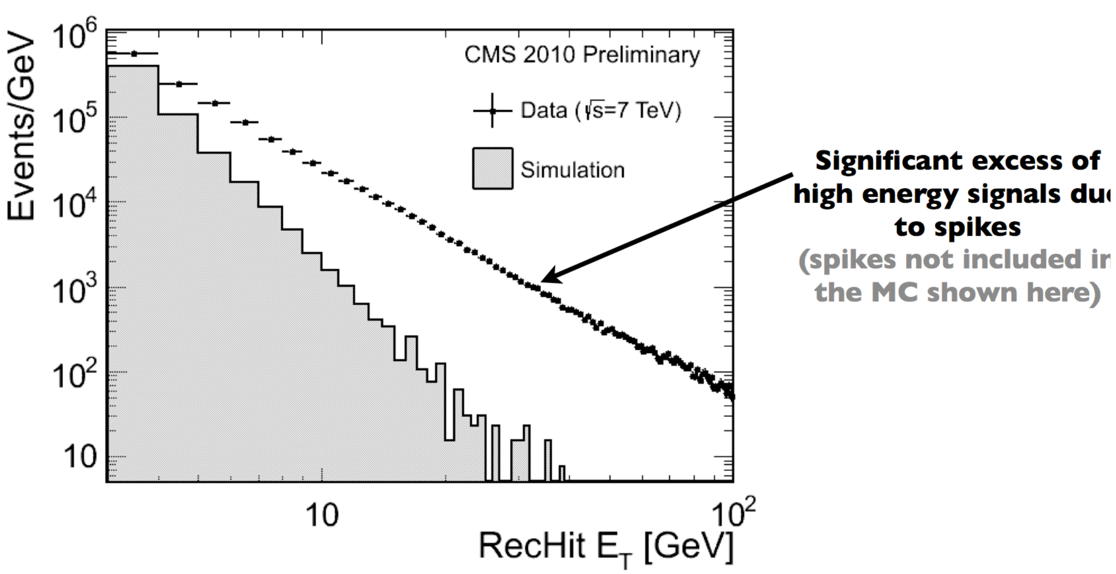
BEMC – Light Yiled assumed ~ 460 x 9 p.e. (9 – PDE x Area of APD compare to 4 SiPMs)
ENF – 1.4 (PANDA TDR), ENC – 50 p.e. before amplification 50, which is state of the art preamp
(initial discussion with Gerard Visser (IUCF))

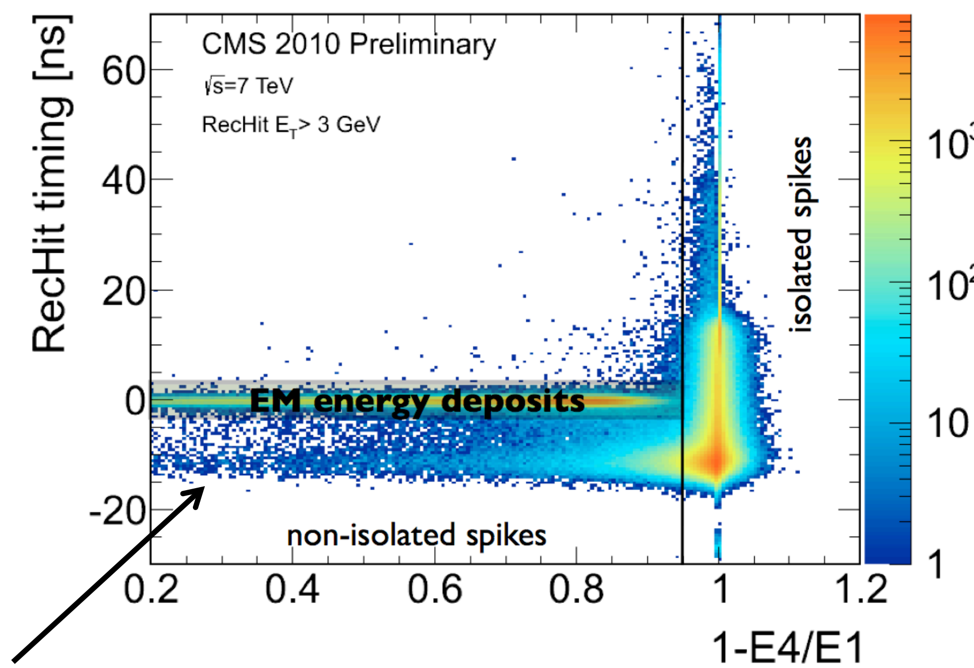
Good and bad things about APDs:





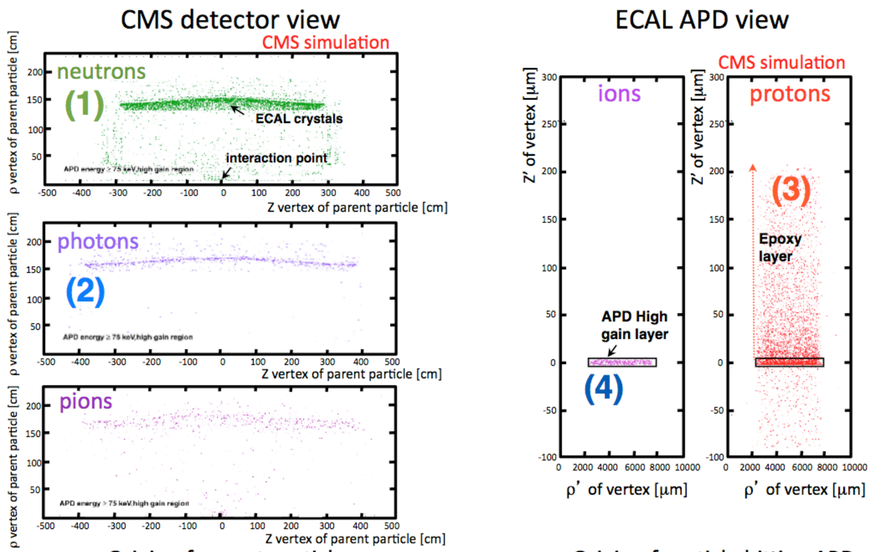
CMS, 50 fb^{-1} -> 2*10^{12} n/cm^2, Noise increase from 43 MeV to 55 MeV





- Reason to use 3HF (green) fibers, slow ~ 7 ns decay time + radiation hard + better match to APDs QE.
- But, there were reports that LY is ~50% of SCSF78

Are SiPMs immune to anomalous signals?

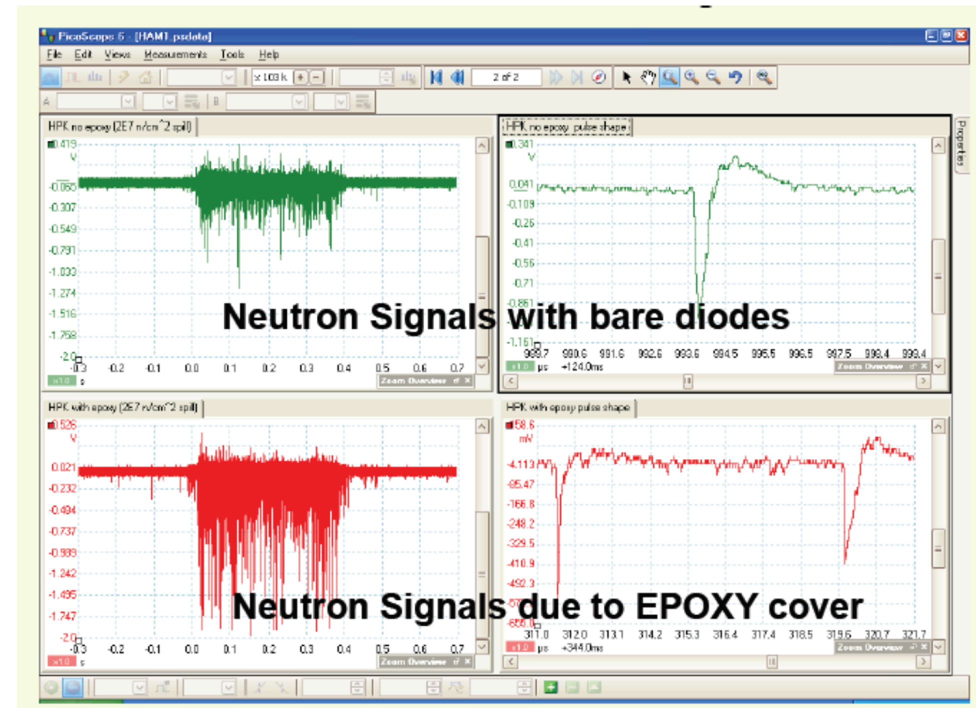


Origin of parent particle
z - distance along beam axis
ρ - distance perpendicular to beam axis

Origin of particle hitting APD
ρ' - distance along APD
z' - distance perpendicular to APD axis

- (1) neutrons produced in the ECAL crystals
- (2) photons produced close to the APD layer
- (3) anomalous signals produced by np scattering in the protective epoxy coating of the APD.
- (4) Ions (silicon nuclei) directly ionize the APD active volume.

Neutron signals in Hamamtsu MPPCs

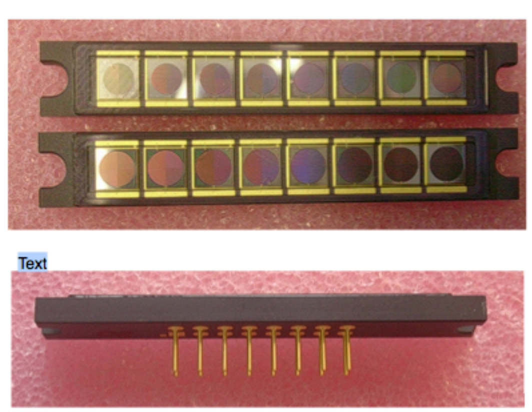


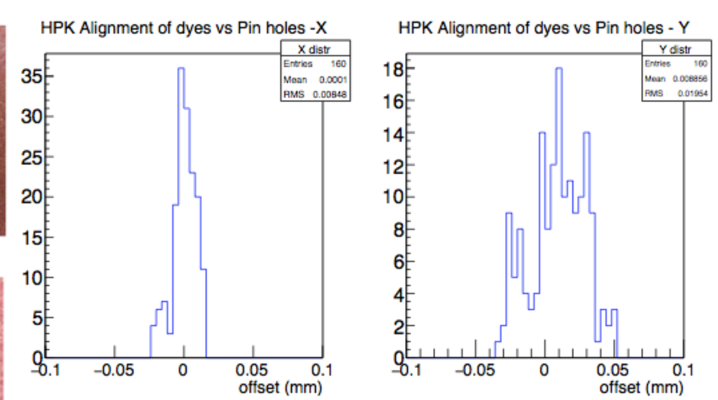
Signals from Bulk? We will try Boron-11 and thinner diode

: on March, Protvino, 16.11.2011 Y. Musienko (Iouri.Musienko@cern.ch) 60

Custom packaged Arrays

With 0.3 mm glass window



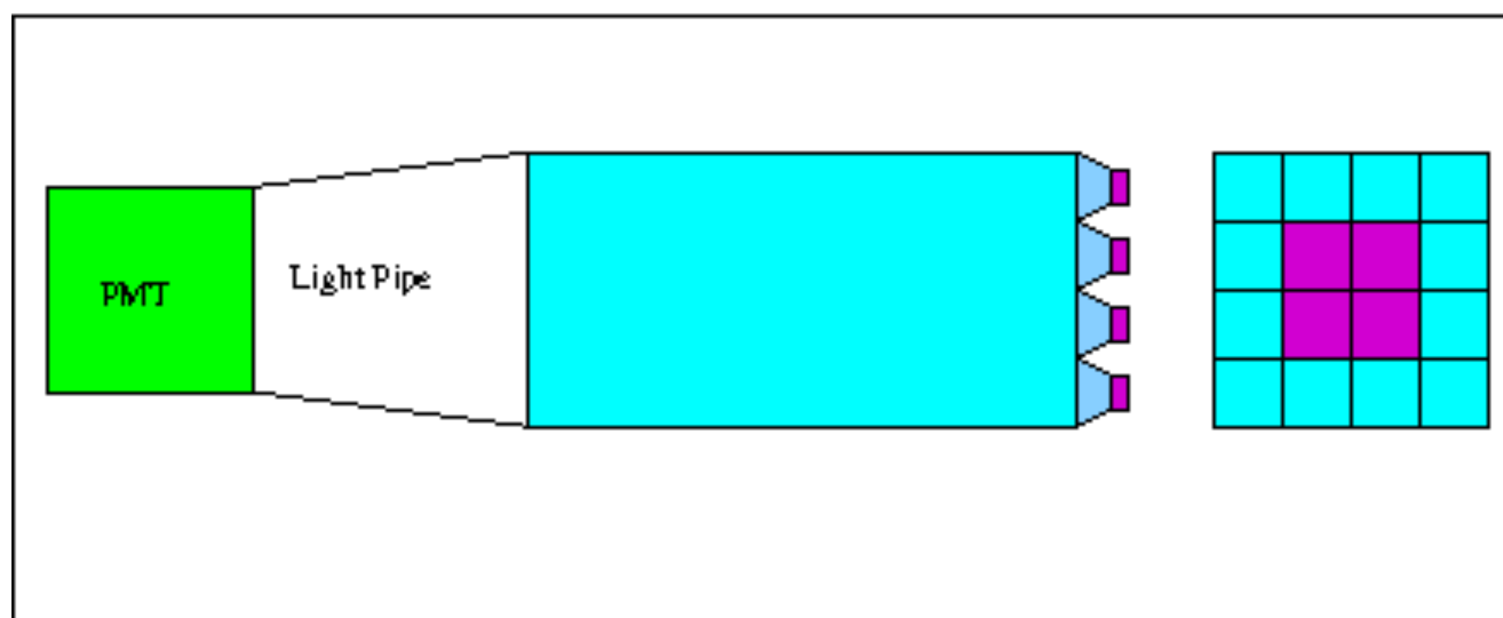


R&D on large dynamic range SiPMs in collaboration with Hamamatsu started in 2010. We now have 15 micron cell devices in 2 sizes, 2.8 mm and 3.3 mm diameter with reps. 27500 and 38500 cells. The 2.8 mm can readout a sum of 4 fibers and the 3.3 mm can readout a sum of 7 fibers

- CMS upgrading HCAL with SiPMs (fluencies up to 10^{12} n/cm^2)
- Epoxy protection window creates problems in both APDs and SiPMs
- Seemingly, mechanism is different (np scattering 50keV p in APDs) vs some sort of scintillation for SiPMs.
- Should we worry about this at EIC environment?

Can we quantify problem using RHIC?

- Equip FEMC prototype with a single PMT readout from the back side + monitoring system.
- Place at STAR IP in forward region with known (MC) and monitored RadMons, (SiPMs itself) neutron background.
- Arrange HT trigger from four central towers readout by silicon sensors.
- Correlate with PMT.
- Ideally want to have both FEMC prototypes readout by APDs and SiPMs at the same time in the same location.
- Timing information probably out of reach for Run16, look only at 'swiss cross' if any abnormal signals observed.



Plan for next year for sampling calorimeters:

- BEMC, CEMC, FEMC – boost LY with compensation from the back side.
- BEMC existing prototype rework at UIUC prepare for single PMT readout.
- BEMC build new device with thicker fibers, single W absorber, optimized with MC, i.e. goal to have as minimal as possible uncertainties for simple data interpretation.
- BEMCs test at FNAL, determine limit on intrinsic resolution, make decision if this technology is good for 'HR' type.
- FEMC build detector with 3HF fibers, optimized for APDs (rad hardness next to the beam pipe, i.e. similar to PWO at back side, possible option for 'HR' readout).
- Quantify rate of anomalous signals for SiPM and APD based readout.

Future planning sampling calorimeters (~ 2018 scale):

Utilize unique opportunity to test complete EMCal system at RHIC (STAR IP) before EIC will start. Need large scale EM+HAD (Forward system as easiest). Use it as a platform for future developments/tests FEEs, DAQ, Monitoring, Slow Control components in 'realistic' experimental environment (discussions about some of these component in progress, but no proposal yet).

Future Plans (BNL PHENIX Group)

- Continue to develop the procedure to build fully projective spacal modules using similar techniques that were used to produce single projective modules. This will be done primarily at BNL and UIUC and will be funded by sPHENIX R&D funds.
- Continue to develop procedures for mass production of spacal modules using the standard 1D projective design. This will be done primarily at THP, but improvements to the process will also be developed at UCLA, BNL and UIUC.
- Construct an 8x8 prototype calorimeter using single tapered modules produced at THP using their mass production method. This prototype will then be tested as part of a beam test of the sPHENIX calorimeter systems at Fermilab in the spring of 2016.
- In parallel, we plan to transfer the technology for producing double tapered modules to THP and adapt this procedure to their mass production process. We will then ask them to produce a second 8x8 array of modules that will be used to construct a second prototype that will be tested at Fermilab later in 2016.
- Carry out additional tests of SiPMs with MeV equivalent neutrons to study the increase in dark current with dose and determine if there is any effect on the PDE at higher doses
- Develop the electronics and control procedures to stabilize the gain of the SiPMs with temperature and with increasing dark current due to radiation exposure. This will involve studies of both electronic control systems as well as cooling and temperature control.

Crystal calorimeters.